

Subcontractor Report

Economic Development Through Biomass Systems Integration in Central Florida

**Final Report
May 5, 1995**

J.A. Stricker and W.H. Smith
*University of Florida
Gainesville, Florida*



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NREL Technical Monitor: H. Brown

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**Economic Development Through Biomass
Systems Integration in Central Florida**

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Edited by

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Summary

Reclaimed phosphate mined land in central Florida has been identified as an area with potential for growing biomass crops. Approximately 73,000 acres of land could be available for biomass production should fuel from biomass systems prove profitable. Environmental impacts from large scale dedicated feedstock supply systems (DFSS) should be minimal provided best management practices are followed. A major environmental benefit for biomass/energy production is the reduction of buildup of carbon dioxide in the atmosphere by recycling carbon dioxide. Utilization of waste streams from ethanol production may be further exploited for production of methane gas or for direct combustion. Another possibility is production of animal feed. Additional research is needed to fully define the possibilities.

A total of six crops have been identified as having the most potential for biomass production. They include the tall tropical grasses; sugarcane, energycane, and elephantgrass (also called napiergrass); leucaena (a woody tropical legume); Eucalyptus, and slash pine. Yields of the different crops vary according to the soil type and range from a high of 22 dry tons per acre, for sugarcane on phosphatic clay soil, to a low of 9 tons per acre for two varieties of Eucalyptus and slash pine. The crop with the lowest estimated production cost per dry ton was leucaena on phosphatic clay at \$3.45 per dry ton. The largest single cost component for biomass production was harvest costs. The most cost effective harvest method appeared to be a high capacity forage chopper.

A regional biomass supply curve was developed with annual production levels ranging from 100,000 to 1,000,000 dry tons. A mixture of 7 crops including 3 varieties of Eucalyptus was assumed. Crops were selected to give a year-round supply of feedstocks to minimize the need for long term storage. Production costs ranged from around \$25.00 per dry ton for 100,000 tons to about \$27.25 per ton for 1,000,000 tons. Production and conversion of 500,000 dry tons of biomass each year is expected to generate \$66,340,000 in total output of goods and services in the local economy plus 606 jobs.

Average transport distances for moving biomass materials from the field to the processing plants are projected to be relatively short. Average distances average about 10 miles. Projected travel time in relation to loading and unloading times was such that hourly rates rather than mileage rates were used to estimate transportation costs. Moisture content of biomass material was the most important factor in determining transportation costs. Field drying of some crops greatly reduced the transportation costs.

Sugarcane appears to be the most versatile biomass crop. Sugarcane may be harvested, pressed to remove approximately 85% of the sugars in the juice. The juice may be fermented into ethanol with conventional technology. The presscake can be hydrolyzed and the hemicellulose converted to ethanol. Cellulose might also be converted to ethanol or the cellulose and lignin might be used in an anaerobic process to make methane. The material might also be burned directly as boiler fuel. The moisture content of presscake, after pressing, is in the range of 60 to 70% which is too wet for efficient combustion. Wet presscake produced only about 2,500 BTU/lb when burned while dried presscake produced almost 6400 BTU/lb. Efficient methods are needed to dry the presscake or the remaining cellulose and/or lignin.

Potential ethanol yield per dry ton of sugarcane is 57 gal for juice, 30 gal from remaining sugars and hemicellulose and 32 gal from cellulose for a total of 119 gal. Presently cost for cellulose conversion is too high to be economically feasible. Research is expected to bring the cost down. With a sugarcane yield of 22 dry tons per acre each acre of sugarcane could produce a total of 2,618 gal of ethanol. The remaining lignin would still be available for direct combustion. With multiple uses of one feedstock the feedstock cost for additional processes is dramatically reduced.

In addition to their use as feedstocks for lignocellulose conversion to ethanol, sugarcane, presscake, elephantgrass, leucaena, and Eucalyptus may prove to be superior feedstocks for valuable products such as high purity cellulose and other chemicals. NREL's Clean fractionation process of separation of materials into constituents of cellulose, hemicellulose, and lignin shows great promise in offering an efficient and economical method opening the way of all three biomass fractions as sources of valuable chemicals and materials. This process could potentially offer glucose and xylose at lower cost for conversion to ethanol or for other marketable products, as well as making the lignin available for profitable uses. Patent applications for this process have been filed and further information is scheduled to be presented in the next few months. Biomass crops such as those grown on reclaimed phosphate are being considered as feedstocks for this process.

Based on project findings, a three phase scale up of a biomass to energy system is proposed. The first phase would be a cooperative effort with an existing conventional ethanol plant in the community. Enough sugarcane (about 250 acres) would be planted to supply the plant with feedstock for about 30 days. Equipment to hydrolyze the hemicellulose in the presscake would be added to the plant. The hemicellulose derived sugars would be fermented with genetically altered bacteria to produce ethanol. Data generated through this process would be used to develop a demonstration plant.

The second phase would include a demonstration plant with an ethanol capacity of 5,000,000 gal per year. It would be a hybrid plant combining conventional dry milling corn to ethanol with two biomass feedstocks; sugarcane and elephantgrass. The plant would operate with sugarcane, sugars and presscake, during the sugarcane harvest season (about 100 days). For the rest of the year (about 230 days) the plant would operate on elephantgrass and corn. The hydrolyzer would be sized to handle all of the presscake as it is being made; which would be about 177 dry tons of sugarcane per day. About 800 to 1,000 acres of sugarcane would be needed.

The elephantgrass would be processed at about 89 dry tons per day, a rate that is equivalent to the daily processing of presscake. About 1,000 to 1,200 acres of elephantgrass would be needed. Output from the plant would be 1.5 million gallons of ethanol per year from sugarcane, 750,000 gallons from elephantgrass, and 2.75 million gal from corn. The estimated net feedstock cost would be \$0.14 for sugarcane, \$0.40 for elephantgrass, and \$0.50 for corn. Total revenue for the plant is estimated to be \$8 million if CO² is sold for \$25 per ton, remaining cellulose/lignin for \$10 per dry ton, Distillers dried grains (DDGs) for \$125 per ton, and ethanol sells for \$1.25 per gal. Total revenue per gal of ethanol is estimated to be \$1.61 per gal and cost are estimated to be \$1.39 per gal.

The third phase would be a commercial plant with a total capacity in excess of 23,000,000 gal per year. The commercial plant would be built around a 5,000,000 gal per year conventional

ethanol plant, coupled with a lignocellulose conversion facility. Approximately 4,500 acres of sugarcane would supply the conventional facility with about 30% of the juice going directly to the plant during the harvest season and 70% concentrated to 70 degrees Brix and stored to operate the plant for the remaining part of the year.

The lignocellulose facility will be sized to convert all of the sugarcane presscake produced each day and be available to convert elephantgrass, leucaena, Eucalyptus or other biomass materials for the rest of the year. Presscake is expected to produce 6,200,000 gal of ethanol and other biomass, 12,400,000 gal. A mix of crops, to spread harvest over most of the year, will be used to better utilize equipment and reduce the need for long term storage of biomass materials. In addition to sugarcane about 10,000 acres of crop would need to be harvested each year to supply the plant, assuming a 68% conversion efficiency.

Objectives

- * Identify land for growing biomass crops and relate land location to location of present and potential conversion facilities.
- * Identify potential biomass crops and estimate production and harvest costs for each crop and soil type.
- * Evaluate environmental impact of large scale biomass production in central Florida and develop best management practices for biomass crops.
- * Evaluate economic and social impact of biomass/energy systems in central Florida.
- * Expand the supply of planting material for selected biomass crops.
- * Evaluate biomass materials handling, storage and processing costs.
- * Determine conversion rates for converting selected biomass materials to energy in various forms.
- * Conceptually combine individual biomass/energy components into an economical, workable system.
- * Identify land and conversion plant requirements for biomass to energy systems from a pilot scale to commercial production.
- * Identify additional research needs for commercialization of biomass to energy systems.

Biomass Production System Components

1. Land Availability and Land Values

W.V. McConnell¹

Land Availability

Initially a large area of Polk and southeast Hillsborough Counties were considered as potential areas for growing biomass crops. Included was an area totalling 600,000 acres. Three categories of land were considered: cropland/improved pasture, unimproved pasture and mined phosphate land. The search soon focused on mined phosphate land in southwest Polk and southeast Hillsborough Counties (see appendix B).

Agriculture in the study area is based largely on range cattle production and citrus. A large part of the area, approximately 210,000 acres, is in unimproved pasture. Much of this land is rented on an annual basis at low rates. Only 1,100 acres is in row crop production, mainly watermelons and cantaloupes. The freeze of 1989 resulted in extensive losses of citrus especially in the northern part of the area. Much of the frozen citrus has been replanted either with citrus or pine trees.

The methodology used to determine land availability was to first send written inquiries to a number of different groups including: fourteen (14) phosphate mining organizations, thirteen (13) current applicants for reclamation funding, thirty nine (39) landowners holding 2,000 acres or more of land, plus, a 5% sample (57) of Polk County landowners with more than 40 acres of land and an ad valorem tax exemption for agriculture. Inquiries were also sent to trustees of the Florida Internal Improvement Fund, Southwest Florida Water Management Dist., Tampa Elect., Co., Florida Power Corp., City of Winter Haven Water and Sewer Dept., Lykes Corp., and Battle Ridge Corp. In addition, personal interviews were conducted with 17 individuals representing the phosphate industry, real estate, land owners, and government agencies.

Only five responses were received from the written enquiries. Due to present commitment to other uses and the lack of a demonstrated market for biomass crops, there was little expressed interest from owners of native land in production of biomass crops. The focus was turned to reclaimed phosphate land since that land is largely uncommitted to other uses and is available in large blocks.

Phosphate mining in Polk and Hillsborough Counties is phasing out. Of 20 mines operating in 1980 only seven will still be operating in 2000. By 2010 only 2 are projected to still be in operation. At the present time, 6 mines have closed since 1984. Much of the land in these 6 mines is still being reclaimed. After the land has been reclaimed and released by the Florida Dept. of Environmental Protection (DEP), Bureau of Mine Reclamation (BMR), the land will either be placed on the market and sold to private owners, leased to farmers, or farmed by the mining company. All three options may be observed in the area today. Presently a farming group has

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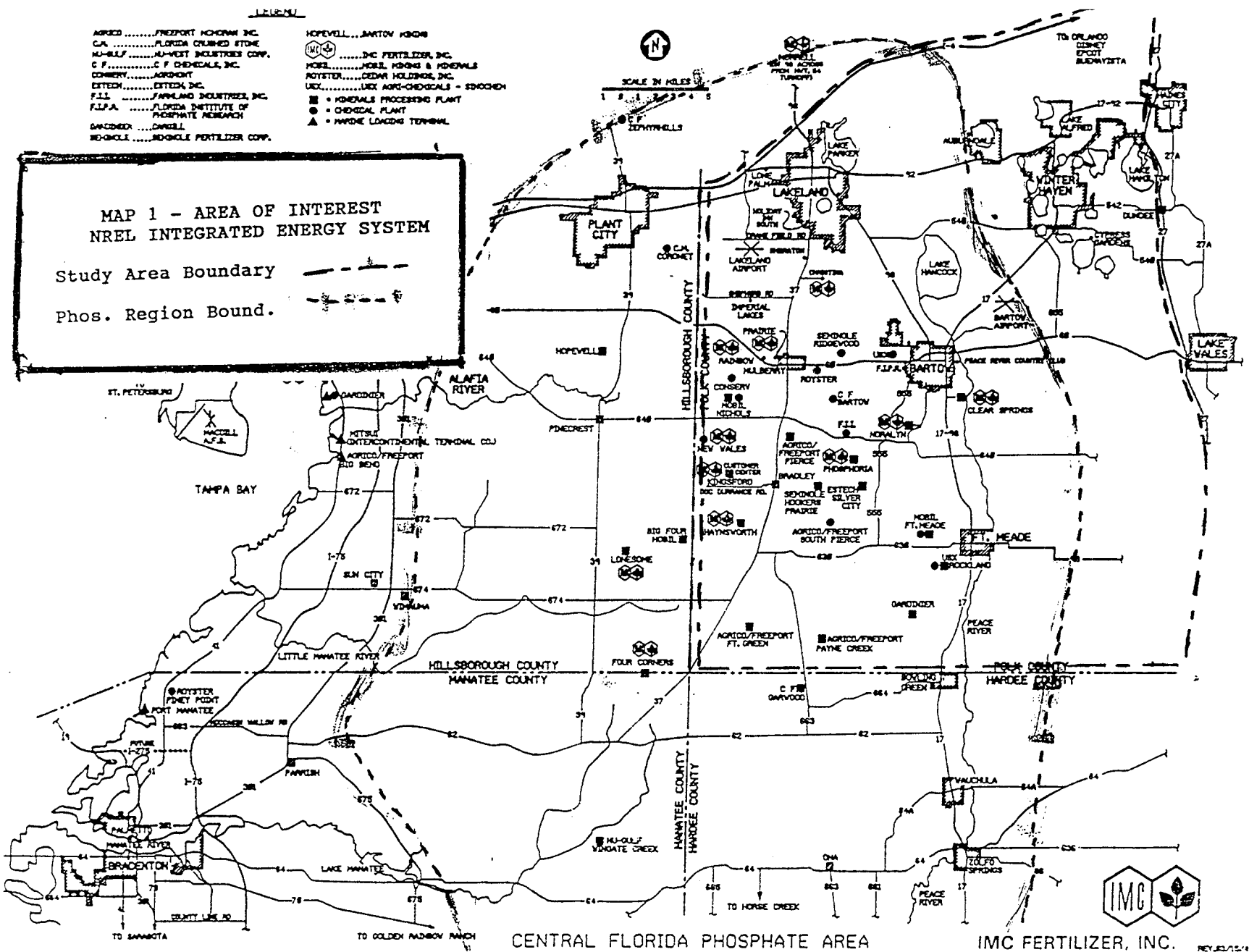


Figure 1-1.

Study area for land availability and land value for biomass crop production in central Florida.

signed a 10 year lease on more than 10,000 acres of clay settling area (CSA), with options on additional land, and are in the process of growing grain to partially supply a newly constructed conventional ethanol plant.

All land mined in Florida after July 1, 1975, called "mandatory" lands, by law, must be reclaimed by the mining company. Land mined prior to July 1, 1975, referred to as "old lands" may be reclaimed using state funds set aside from a severance tax on phosphate ore. The state administered "old lands" fund currently has a balance of \$112,000,000 of which \$69,000,000 has not yet been allocated. Additional revenues of about \$18,000,000 are being added each year. It is anticipated that, barring legislative changes, there will be sufficient funds to reclaim all old lands.

Two land forms are included in the mined phosphate land category: clay settling areas; dewatered clay slurry pits, mined out areas (MOA); areas of leveled overburden. Potential lands available are included in table 1-1. The mined lands are considered to be more fertile than native lands. Clay settling areas are the most fertile and the mined out areas are considered to be moderately fertile.

Table 1-1. Land Available for Biomass Production in Central Florida

Land Form	Total	Reclaimed ^a	Available ^b
-----acres-----			
Clay Settling Area	92,000	44,000	37,000
Mined Out Areas	88,000	72,000	36,000
Sub total	180,000 ^c	116,000	73,000
Crop Land/Imp. Past.	180,000 ^d	NA	^e
Unimproved Past.	210,000 ^d	NA	^e

^a Reclaimed, under contract or filed for approval.

^b Estimated to be environmentally or economically available.

^c Increasing at the rate of 5,000 acres per year.

^d Generalized aggregate estimates by Natural Resources Conservation Service and County Extension Service for all of Polk County. Data are for an undefined resource including "woodland pasture" and "grasslands" - a gross indication of the possible extent of the resource.

^e Location and availability unknown. Not considered significant for macroplanning.

Included in the resource base are lands that are reclaimed, have BMR approval for reclamation or are covered by "intent to reclaim" notice under the old lands program. An unknown fraction of this land will be unavailable for biomass production because of environmental coordination needs, or because of development pressures, in the case of MOAs. Based on discussions with BMR personnel and study of *Regional Conceptual Plan for the Southern Phosphate District* (Cates, 1992) the fraction has estimated to be 15% for CSAs and 50% for MOAs.

Land Values

Information gathered in interviews and from land appraisers plus other documents were consolidated into table 1-2. Tract sales of any size invariably involved more than one land form. No sales were found of clay settling areas only. The value of \$1,500 for CSAs is highly speculative. Rental values for CSAs for energy crop production is based on a single 10 yr lease for 3,500 acres plus options on additional land.

Information on sale and lease values for MOAs is readily available. A Univ. of Florida, IFAS study of Polk County pasture rentals (*Survey of Pasture Rental in Polk County - 1991* Stricker, *et al.*) showed the average per acre rental in the southwest part of the county, an area primarily MOAs, to be \$7.54 per acre. This rate is consistent with rate quoted by land managers, area land appraisers and brokers, but below the rate for large tracts. It is this writers judgement that annual pasture rental rates do not represent values for long-term leases for energy crop production on large areas. Land managers were reluctant to set values, as a result, the long term lease values in table 1-2 reflect a best judgement.

Table 1-2. Land Values for Biomass Production

Land Type	Market Value	Rental Value/Yr
	-----\$/Acre-----	
Clay Settling Areas	1,500	20.00
Mined Out Land	1,275	15.00

The spacial distribution of available lands seems to result in natural groupings around existing or planned bio-fuel consumers. These development centers (see appendix B) and their fuel-sheds could serve as the basis for the second phase of this study.

One of the most important of these options involves three very large electrical generating facilities built, or soon to be built in southwestern Polk county. Initial capacity for these facilities total 3,000 MW with planned expansion to over 5,000 MW. The construction of these fossil fuel based facilities in a large area of unused land suitable for dedicated feedstock supply system (DFSS) offers an opportunity for an integrated fossil/renewable fuel system. By using the host's infrastructure (management, technical, transportation, and operating systems) the satellite system could achieve substantial saving in installation and operating costs. Such a symbiotic arrangement would offer the host a number of advantages (diversification, PR, mitigation of CO₂ emissions, or earned SO_x emission credits). It is strongly recommended that the planning team consider this as a preferred option.

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2. Biomass Crops and Production Methods

Gordon M. Prine and Donald L. Rockwood²

University of Florida researchers have 12 yrs experience growing perennial tall tropical grasses and leucaena on phosphatic clay soils in central Florida and at other locations in Florida. Because of this experience, information was available which aided other researchers in their efforts on this project. Information on biomass yields of different tall grass genotypes at three Florida locations for the 1992 and 1993 growing seasons is presented in appendix C., along with chemical composition of the different tall grasses over the two yr period.

Table 2-1. Suitability of Crops to Specific Soils^a

Crops	-----Soil Types-----		
	Phosphatic Clay	Overburden	Crop Land
Elephantgrass	1	1	1
Sorghum	1	1	1
Sugarcane	1	2	2
Energycane	1	2	2
Leucaena	1	1	1
E. grandis	3	1 ^b	1 ^b
E. camaldulensis/tereticornis	1 ^b	1 ^b	1 ^b
E. amplifolia	1 ^b	1 ^b	1 ^b
Pinus	3	1 ^b	1 ^b

^a Suitability Class:

1-highly suitable

2-moderately suitable

3-unsuitable

^b Assumes site is amended or prepared as required.

Crops selected as having potential for energy in the central Florida area include: elephantgrass (also known as napiergrass), energycane, sugarcane, and forage & sweet sorghum. Leucaena was selected as a short season woody crop, especially for phosphatic clay soil. Other woody species selected include: *Eucalyptus grandis*, (EG) *Eucalyptus camaldulensis*, (EC) *Eucalyptus tereticornis*, (ET) *Eucalyptus amplifolia*, (EA) and slash pine. The four species of *Eucalyptus*

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grow quickly and have adequate freeze resilience for appropriate regions of the state. Suitability of the different crops to three soil types are listed in table 2-1.

Commercial use of *Eucalyptus* depends on genetic improvement and development of propagation options such as seedlings, rooted cuttings, and micropropagules. A typical tree in a seed orchard yields one pound of seed, which is sufficient to plant 300 acres. Various superior clones have been identified and may be multiplied by rooting of cuttings or by micropropagation. One acre of clone bank may produce enough cuttings to plant 100 acres annually. Several EG clones available as plantlets from a tissue culture lab have been used to establish clonal plantations in southern Florida since 1987.

Table 2-2. Yield Estimates and Expected Stand Life for Biomass Crops - Not Irrigated.

Crop	Phos. Clay	Overburden	Crop Land
-----dry matter----- Ton/A			
Elephantgrass	18.0-6yr ^a	18.0-6yr	18.0-6yr
Energycane	20.0-6yr	16.0-5yr	15.0-5yr
Sugarcane	22.0-6yr	18.0-4yr	18.0-4yr
Forage Sorghum - biomass ^b	11.0-1yr	10.0-1yr	10.0-1yr ^c
Leucaena	16.0-10yr	15.0-10yr	12.0-10yr
<i>Eucalyptus grandis</i>	--	14.0-3c	13.0-3c
<i>E. camaldulensis</i> / <i>E.</i> <i>tereticornis</i>	9.0-5c ^d	9.0-5c	9.0-5c
<i>E. amplifolia</i>	11.0-6c	10.0-4c	10.0-4c
Pinus	--	9.0-8	9.0-8

^a 6yr refers to the expected life of the stand.

^b One harvest, does not include ratoon crop.

^c Serious *Pythium* and nematode problems reported - yield data not included.

^d 5c - 5 indicates number of years from establishment to harvest, c indicates coppice regrowth with 20% more yield.

Production functions for the woody species were developed based on planting stock type, planting density, site/culture, and age. The most realistic production options (including planting stock type and cost, planting density, site, cultural option, rotation age and season of harvest) were developed to estimate yields on different land types being considered. Results are presented in table 2-2.

Elephantgrass and sugarcane culture are similar. Both are perennial crops and are propagated from hardened stem pieces. This limits the number of acres that may be planted from one acre of nursery to about 10 for each acre of nursery. Expected productive life for the two crops is from 4 to 6 yr. Leucaena may be propagated from seed. Leucaena is expected to have an indefinite productive life. For purposes of this study a 10 yr life was used.

A mixture of both herbaceous and woody species in a DFSS is recommended as a way to more nearly provide a constant supply of biomass material to a conversion facility.

3. Estimated Establishment and Growing Costs

James A. Stricker³

Soils, Crops and Production Systems

The number of soil types selected for biomass production in central Florida was narrowed to three: reclaimed phosphatic clay, reclaimed overburden, and native crop land. Phosphatic clay as a soil is unique in Florida where natural soils are typically sandy or organic in nature. The clay has many desirable characteristics including high water holding capacity which greatly reduces the need for supplemental irrigation. Phosphatic clay is also naturally fertile with high levels of phosphorus, calcium, magnesium and potassium. Adequate amounts of minor elements are also present. Soil pH varies from 7 to 8 which is slightly higher than optimum for most crops. Mild manganese deficiency symptoms have been observed in some legume crops, however, no yield response has been documented as a result of foliar applications of manganese. The nature of the clay can limit field access during wet periods and limit maintenance and harvest operations during critical periods for some crops. (Shibles *et al.* 1994; Stricker, 1991)

Overburden is made up of quartz sand and clay lenses (kaolinite and montmorillonite) and the primary phosphate mineral apatite. Kaolinite is the principle clay in overburden. It is rich in oxides of iron (FeO_3), magnesium (MgO), and potassium (K_2O) (Ecolmpact, Inc., 1980). Depth of soil material varies from 1.5 to 20 ft. Soil color varies from white and light gray to dark brown and black. Soil texture ranges from sand, fine sand, loamy sand, sandy loam, sandy clay, and clay. There is no orderly sequence of horizons. Available water holding capacity, while generally low, increases with clay content. Internal drainage is also variable and is inversely related to clay content (Soil Survey Staff, 1987).

Most native cropland is used for improved pasture in Polk County. Only about 1,000 acres of row crop is grown. A number of soil types may be candidates for biomass production. The soils range from well drained sandy ridge soils to less well drained sandy flatwoods soils. In general, these soils have a pH in the range of 3.6-6.5, they are relatively infertile with low water holding capacity.

Potential biomass crops were determined by agronomists and foresters and include: elephantgrass, sugarcane, sorghum, leucaena, *Eucalyptus*, and pine. Elephantgrass, sugarcane, sorghum, and leucaena are grown with agronomic methods while *Eucalyptus* and pine are grown with forestry methods. Costs for establishing and growing *Eucalyptus* and pine were determined by Dr. Don Rockwood of the School of Forest Resources and Conservation at the Univ. of Florida and are reported elsewhere. Costs for establishing and maintaining agronomic crops were determined with the aid of a computerized budget generator developed by the faculty of the Food and Resource Economics Dept. at the Univ. of Florida.

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4. Potential Harvest Methods

Richard Schroeder⁴

Crop Characteristics

Row spacing, number of stems per acre, size and height of stems for herbaceous crops and leucaena were determined by Dr. Prine. Results are shown in table 4-2.

Table 4-1. Plant Size and Row Spacing for Biomass Crops

Crop	Row Spacing	Tall Shoots/acre	Plant Height	Stem Size <u>Max.</u> Diameter
		(1000's)	(ft.)	(in.)
Sugarcane ^a	60 inch	24-32	13-18	2.4
Energy Cane ^a	30 to 42 inch	32-44	13-18	2.0
Elephantgrass ^a	30 to 42 inch	36-44	13-18	1.6
Sorghum (sweet or forage)	30 to 42 inch	26-34	10-13	1.4
Leucaena (annual growth)	30 to 42 inch	14-16	16-20	3.0
(up to 4 yrs age)	30 to 42 inch	10-14	20-26	5.0

^a Sugarcane can be planted in 30 to 42 inch rows like energy cane and elephantgrass. Elephantgrass and energy cane can be planted in wider rows. The spacing needed by harvesting equipment will probably determine row spacing.

Machine Capacity

Conversations with project developers of both combustion and ethanol projects revealed that a minimum of 30,000 bone dry tons (BDT) of biomass materials per year will be needed. Although closed loop dedicated crops may be integrated into existing facilities in smaller quantities, feasibility of a new enterprise is being considered for this study. As a result, the 30,000 ton figure will be used. (For more detail see appendix E.)

Limitations on harvest season (5 months per year) reported by Univ. of Florida researchers will increase the required machinery capacity. About 120,000 green tons (75% moisture) must be harvested in five months, or approximately 125 work days.

While it can be argued that this requirement will force operations into 7 days per week, (which is closer to 150 days) some consideration must be given to transit, and weather related

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Table 4-2. Harvesting Machinery, Cane-Woody-Harvested in Billets

Machine	Cut/Billet	Billet Chipper	Wagon	Wagon	Wagon	Wagon	Farm Tractor	Service Truck	Fuel Tank
Manufacturer	Austoff	Morbark	Varies	Varies	Varies	Varies	John Deere	Ford	Any
Model Number	7700	3036 E-Z	Varies	Varies	Varies	Varies	6300	F 350	
Specification	Track- Type	Drum Type	25ft	25ft	25ft	25ft	4wd cab	One Ton	500 Gal
Horsepower	300	425					75		
Machine Purchase Cost	\$220,000	\$140,000	\$14,000	\$14,000	\$14,000	\$14,000	\$39,300	\$45,000	\$3,000
Estimated Useful Life, Hr	7500	5000					7500	7500	
Estimated Useful Life, Yrs	5	5	10	10	10	10	7	5	7
Machine Capacity, Green Tons per Hr	80	50							
Machine Capacity, Acres per Hr	2								
Machine Availability-% of Total Time	85%	75%					90%	90%	
Expected Use in Hrs per Year	600	1200							
Expected Repair Costs per Year	\$9,000	\$28,000	\$1,000	\$1,000	\$1,000	\$1,000	\$2,500	\$1,500	
Fuel Type	Diesel						Diesel	Diesel	
Fuel Consumption per Hr	6	6					3	1	

AGSYS Budget Generator Program

The AGSYS Budget Generator is designed to estimate the cost of producing a specific crop through simulation of production decisions and activities over a period of time. Material and machinery databases are used to calculate costs for all necessary production inputs including: agricultural chemicals, labor, machinery use, contracted services as well as overhead, depreciation, and interest on working capital.

The material and machinery databases are used by AGSYS to create budgets. The material database contains cost information for inputs including seed, fertilizer, and pesticides. The machinery database has all the technical information needed to generate both fixed and variable costs for farm equipment used to grow the crop. When building a budget, AGSYS pulls information from both material and machinery databases and stores it as a budget file.

Table 3-1. Summary of Budgeted Costs for Establishing and Maintaining Biomass Crops on Three Soil Types in Central Florida

Crop	Soil Type	Yield/Acre (dry ton)	Est. Cost (dry ton)
Sugarcane	Phos. Clay	22	\$ 8.04
Forage Sorghum	Phos. Clay	11	15.91
Leucaena	Phos. Clay	16	3.45
Elephantgrass	Phos. Clay	18	9.69
Sugarcane	Overburden	18	13.52
Forage Sorghum	Overburden	10	22.61
Leucaena	Overburden	15	5.59
Elephantgrass	Overburden	18	11.27
Sugarcane	Crop Land	18	13.62
Forage Sorghum	Crop Land	10	22.16
Leucaena	Crop Land	12	7.28
Elephantgrass	Crop Land	18	11.59

Crop production budgets bring together information from material and machinery databases into operational records which serve to simulate a crop production plan. Each operation has a name, date performed, and a list of production input items. For example; plowing on 10/15/95, with 125 hp tractor, 5 bottom plow, traveling at 3.5 mph. Budgets are a collection of one or more of these

operation records. In addition to operation records a budget includes a set of economic parameters that are used to calculate costs such as depreciation and interest expense.

Establishment and Maintenance Costs

To develop budgets for the various biomass crops, basic assumptions were listed for each soil including need for and frequency of irrigation, area of each soil type devoted to drainage ditches, and row width for planting each crop. Specific field operations, materials and equipment used for each operation was determined. Ground speed for each field operation was also determined so AGSYS could calculate the time required to cover an acre with each operation.

A detailed list of field operations and materials used for each crop and each soil is presented in appendix D. For perennial crops, separate budgets were developed for establishment and annual maintenance operations. Perennial crop establishment costs were amortized over the expected life of the stand with interest charged at 8% on the unused balance. Results for four crops on three soil types are reported in table 3-1.

Cost figures presented in table 3-1 cover a charge for land, labor and capital but do not reflect a charge for management or profit. Costs per dry ton produced appears to be lower for high yielding perennial crops and higher for annual crops.

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Table 4-3. Harvesting Machinery, Cane-Grass-Woody-Chopper Harvesting

Machine	Cut/Chop	Wagon	Wagon	Wagon	Wagon	Tractor	Truck
Manufacturer	Claas	Varies	Varies	Varies	Varies	John Deere	Ford
Model Number	Jaguar	Varies	Varies	Varies	Varies	6400	F 350
Specification	Willow hd.	covered	covered	covered	covered	4wd cab	One ton
Horsepower	250					85	
Machine Purchase Cost	\$285,000	\$22,000	\$22,000	\$22,000	\$22,000	\$41,600	\$45,000
Estimated Useful Life, Hrs	7000					7500	7500
Estimated Useful Life, Years	6	10	10	10	10	7	5
Machine Capacity, Green Tons per Hr	40						
Machine Capacity, Acres per Hr	2						
Machine Availability-% of Total Time	75%					90%	90%
Expected Use in Hrs per Year	1500						
Expected Repair Costs per Year	\$23,000	\$1,000	\$1,000	\$1,000	\$1,000	\$2,500	\$1,500
Fuel Type	Diesel					Diesel	Diesel
Fuel Consumption per Hr	8					4	1

Table 4-4. Harvesting Machinery, Grass-Cut-Dry-Bale System

Machine	Cutter	Farm Tractor	Farm Tractor	Windrow Rake	Round Baler	Tractor w/ Loader	Platform Wagon	Platform Wagon
Manufacturer	John Deere	John Deere	John Deere	John Deere	John Deere	John Deere	John Deere	John Deere
Model Number	240	6300	6300	700	535	6300	770	770
Specification	Rotary	4wd cab	4wd cab		5-6ft bales	4wd cab	14 ton	14 ton
Horsepower		75	75		75 reg	75		
Machine Purchase Cost	\$5,000	\$39,300	\$39,300	\$10,600	\$21,500	\$47,500	\$3,600	\$3,600
Estimated Useful Life, Hrs	10,000	7,500	7,500	10,000	7,000	7,500	10,000	10,000
Estimated Useful Life, Years	10	7	7	10	7	7	10	10
Machine Capacity, Green Tons per Hr	100			100	60			
Machine Capacity, Acres per Hr	3			3	2			
Machine Availability-% of Total Time	90%	90%	90%	90%	90%	90%	95%	95%
Expected Use in Hrs per Year	600	800	800	600	1,000		300	300
Expected Repair Costs per Year	\$1,000	\$2,500	\$2,500	\$1,000	\$2,000	\$2,500		
Fuel Type		Diesel	Diesel			Diesel		
Fuel Consumption per Hr		3	3			3		

problems. As a result, the lower number of 125 days was used. In addition, the months listed are those of shortest daylight hrs, so no more than 10 operating hrs can be assumed on average. From the information above, for any of the three systems (cane, grass, or woody stems), capacity is needed of $120,000/125/10=96$ tons per hour. At a capacity factor of 80%, a capacity of 120 green tons per hour would be required.

Field Conditions

Field conditions in the areas to be harvested are considered to be flat, rock-free, subject to flooding and poor traction. Access to fields will be unimpeded with wide alleys and paved roads. In discussions with equipment manufacturers, reference was made to ground instability and the need for floatation equipment in development of sites.

McConnell, in his land availability study, identified two primary land types; clay settling areas (CSA's) and mined out areas (MOA's). The CSA's are basically dewatered slime ponds, while the MOA's are areas of overburden where the mineral has been removed and the land re-leveled.

For both of these land types drainage will be a problem. In central Florida the rainfall is seasonally less in fall and winter than in summer. However, during harvest time many rainfall events of 1 in or more can be expected.

CSA's present an additional challenge. The ground consists of a hardened crust over a 'bottomless' quagmire of high-clay, water saturated materials. An interview with Florida Land Reclamation Co, a company specializing in phosphate land reclamation, revealed that standards for reclamation of CSA's are that when complete the soil is able to support the weight of "average farm equipment". As a result high flotation wheels on harvesting equipment will be the minimum required. Track-type machines would be better. In addition, the land will probably not support on-road type trailers for transport of biomass materials. This information was used in determining machinery requirements.

Desired Product Characteristics

Moisture in biomass used for combustion is a major problem, leading to inefficiency and emissions issues. Moisture in biomass for ethanol production is not a problem.

Some kind of drying process will be needed for combustion fuel. For woody stems, transpiration drying by advanced felling is a common practice in some areas. Operations are almost identical for either fresh or desiccated tree harvesting, so only one system is examined.

5. Estimated Harvest Cost

James A. Stricker⁵

AGSYS Budget Generator

The AGSYS budget generator is described in section 3 of this report. Harvest costs for hay harvesting, chopper harvesting and billet harvesting were estimated with the AGSYS program. (Estimated harvest costs for feller/bunching are supplied by Dr. Don Rockwood of the School of Forest Resources and Conservation at the Univ. of Florida and is reported in table 6-4 in this report.) Data on equipment selection was provided by Mr. Richard Schroeder, Kenetech, Inc. while yield data for each crop and soil type was based on extensive research and supplied by Dr. Gordon Prine of the Univ. of Florida Agronomy Dept. Acres harvested per hour was calculated outside of the budget model and was based on crop yield and material handling capacity of the harvesting machine in tons per hour. The model used a field efficiency factor of 70% to calculate an effective harvest rate. For example, a machine with a capacity of 120 green tons per hour would effectively harvest 84 tons per hour. Estimated harvest cost for 24 combinations of crop, soil type and harvest method is reported in table 5-1. Individual crop budgets are shown in appendix F.

Sugarcane Harvested as Billets

Projected yield of sugarcane is 22 dry tons per acre on CSA, and 18 tons per acre on the other two soil types. Standing sugarcane will be harvested with an Austoff 7700 track-type billet harvester. Harvest capacity of the Austoff 7700 billet harvester is expected to be about 80 green tons per hr. billets measuring about 18 to 24in will be elevated into tandem dump wagons being pulled alongside the harvester by a 75 hp tractor. Tractor and wagons will move to the edge of the field and transfer the billets for transport to a processing plant. Billets must be processed within 24 hours of harvest to reduce loss of sugars.

At a processing plant, the billets will be ground and pressed. Sugar laden juice will go directly to an ethanol plant for fermentation. The presscake may 1) go to an ethanol plant for conversion of the hemicellulose or cellulose to ethanol, 2) go to a plant for conversion to methane gas, 3) piled and packed for ensiling for later conversion to ethanol. Moisture level of presscake will be too high for direct combustion.

Harvesting Leucaena as Billets

Annual coppice growth of leucaena is expected to yield 16 dry tons on CSA's, 15 dry tons on MOA's and 12 dry tons on crop land. Leucaena will be harvested with an Austoff 7700 track-type billet harvester. Billets measuring 3-4 ft long will be

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Table 5-1. Budgeted Costs for Harvesting Biomass Crops in Central Florida

Crop	Soil	Harvest Method	Dry Tons Harvested/ Acre	Harvest Cost/Ton	Approx. Moisture at Farm
Sugarcane	Phos. Clay	Billets	22	\$21.50	75%
Sugarcane	Phos. Clay	Forage Chopper	22	13.67	75%
Sugarcane	Overburden	Billets	18	21.39	75%
Sugarcane	Overburden	Forage Chopper	18	13.75	75%
Sugarcane	Crop Land	Billets	18	21.39	75%
Sugarcane	Crop Land	Forage Chopper	18	13.75	75%
Sorghum	Phos. Clay	Billets	11	21.89	75%
Sorghum	Phos. Clay	Forage Chopper	11	14.16	75%
Sorghum	Overburden	Billets	10	23.70	75%
Sorghum	Overburden	Forage Chopper	10	13.99	75%
Sorghum	Crop Land	Billets	10	23.70	75%
Sorghum	Crop Land	Forage Chopper	10	13.99	75%
Leucaena	Phos. Clay	Billets ^a	16	31.76	15-20%
Leucaena	Phos. Clay	Forage Chopper	16	11.92	70%
Leucaena	Overburden	Billets	15	31.30	15-20%
Leucaena	Overburden	Forage Chopper	15	12.12	70%
Leucaena	Crop Land	Billets	12	36.43	15-20%
Leucaena	Crop Land	Forage Chopper	12	12.22	70%
Elephantgrass	Phos. Clay	Natl. Dry & Bale	18	18.79	15-20%
Elephantgrass	Phos. Clay	Forage Chopper	18	13.73	75%
Elephantgrass	Overburden	Natl. Dry & Bale	18	18.79	15-20%
Elephantgrass	Overburden	Forage Chopper	18	13.73	75%
Elephantgrass	Crop Land	Natl. Dry & Bale	18	18.79	15-20%
Elephantgrass	Crop Land	Forage Chopper	18	13.73	75%

^aBillets naturally dried and then chipped with Morbark 3036 E-Z chipper

elevated into tandem dump wagons being pulled alongside the harvester by a 75 hp tractor. Tractor and wagons will move to the edge of the field and billets dumped into a windrow to dry. The billets may be chipped after drying for 4-6 weeks or stored in the windrow for up to 6 mos. The billets may be chipped with a Morbark 3036 E-Z self loading chipper. The chips will then be transported to the conversion facility for direct combustion or storage until needed.

Sugarcane/Elephantgrass Harvested with Self Propelled Forage Chopper

Projected yield of elephantgrass is 18 dry tons per acre on all soil types while sugarcane yield has been discussed earlier. Standing sugarcane or elephantgrass will be chopped with a Claas Jaguar forage chopper, equipped with a willow head. Chopped material will be blown into a self-unloading wagon pulled behind or to the side of the chopper. There has been some discussion on the harvest capacity of the Claas Jaguar harvester. Schroeder reports a capacity of 40 tons per hr in section 4 of this report. Discussions with Claas Company officials revealed that the machine has a capacity of 170 green tons per hr when harvesting corn for silage. For harvesting sugarcane and elephantgrass a capacity of 160 green tons per hr was used. When a 70% field efficiency factor is applied to the 160 ton per hour capacity an effective harvest rate of 112 tons per hour was determined.

Chopped material will be moved from the field with a 75 hp tractor pulling a self-unloading wagon. Chopped sugarcane will be unloaded into a feeder and fed into a series of screw presses located adjacent to the field. Sugarcane juice will be pumped directly into a tank truck and transported directly to an ethanol plant. Presscake may also be loaded onto trucks and transported to either an ethanol or methane plant. It may also be ensiled for storage on the edge of the field.

Chopped elephantgrass would be transferred to a trailer at the edge of the field and transported directly to an ethanol plant for direct conversion. Moisture level would be too high for direct combustion. It might be possible to store chopped elephantgrass as silage, for later conversion, however, moisture level is likely to be too high for making good silage.

Harvesting Leucaena with a Forage Harvester

Standing leucaena will be chopped with Claas Jaguar forage chopper equipped with a willow-head. The harvest capacity for a forage chopper in leucaena is estimated to be 140 green tons per hour. Chopped leucaena will be blown into a self-unloading forage wagon pulled behind or alongside the harvester. Loaded wagons will be moved to the edge of the field and transferred to trailers for transport to a conversion facility. Fresh chopped leucaena is expected to have a moisture level of around 70%. While this material would be suitable for conversion to ethanol, the high moisture level makes the material unsuitable for direct combustion. If it were to be stored in windrows, it would be necessary to turn the windrows frequently to encourage drying and prevent decay. Cost for a windrow turner has not been included in this study.

Harvesting Elephantgrass as Hay

Standing elephantgrass will be mowed with a 75 hp tractor and John Deere model 240 mower and left in place. After drying or several days, the material will be turned with a 75 hp tractor

and John Deere model 700 rake. To aid drying, the material will be turned two more times before baling. When sufficiently dry (15-20% moisture) the elephantgrass will be baled with a 75 hp John Deere tractor and model 535 large round baler. Bales will weigh an average of 1,500 lbs. At a moisture level of 15% elephantgrass will yield an average of 28 bales per acre.

Bales will be moved from the field by loading onto John Deere model 770 wagons in the field with a tractor and front end loader. Two wagons will be pulled behind each tractor. A second tractor and front end loader will unload bales and place them in a temporary storage area on the edge of the field or load them onto trailers for transport to conversion facilities.

Economic and Social Issues

Economic analysis of the proposed biomass energy systems in central Florida included three major tasks; (6) Estimation of biomass production costs and establishment of a regional biomass supply curve; (7) Appraisal of the market for ethanol and electrical power in Florida; and (8) Economic impact of biomass/energy systems (evaluation of personal income and employment impacts of biomass industry development). Issues related to production, harvesting, transportation and storage were studied and analyzed as depicted in Figure 6-1. The characteristics of integrated biomass systems in central Florida, were summarized in tabular form to show activities, inputs, outputs, and dominating issues (Table 6-1).

6. Estimation of Production Costs and Establishment of the Regional Supply Curve for Biomass Products in Central Florida

Mohammad Rahmani, Alan Hodges, and Clyde Kiker⁶

The potential supply in the region was estimated on the basis of costs for production and delivery of biomass products. The relationship between the volume of biomass and the cost of producing it needs to be defined in order for the regional supply curve for biomass to be established. Since at the present time, mined lands are the major source of land available in this area and these lands are homogenous, there are few factors that contribute to cost variances based on production volumes. Differences in fertility and structure of phosphatic clay and overburden soils, distances of these lands to ethanol or electric power plants, and, to some degree, the planting constraints due to availability of propagating materials for various biomass crops, were the main factors having some impact on costs as a function of production volume. Some of these factors do not affect the production cost significantly. Nevertheless, over time there may be other factors that affect the cost of production, when other lands in this area, such as croplands, may be considered for biomass production. The most important factor will be the rental value of land, but at the present time there are not enough data to support any land rent estimates for biomass production beyond the mined lands in this area. A regional supply curve was estimated based on data and information obtained from other subproject leaders or other sources, and assumptions that will be explained further in this report.

Data and information were collected on all aspects of potential biomass crops that can be grown in the area, as well as suitable land available. A spreadsheet format was used for compiling, collecting and analyzing information on cost components and yields for various soil and plant types.

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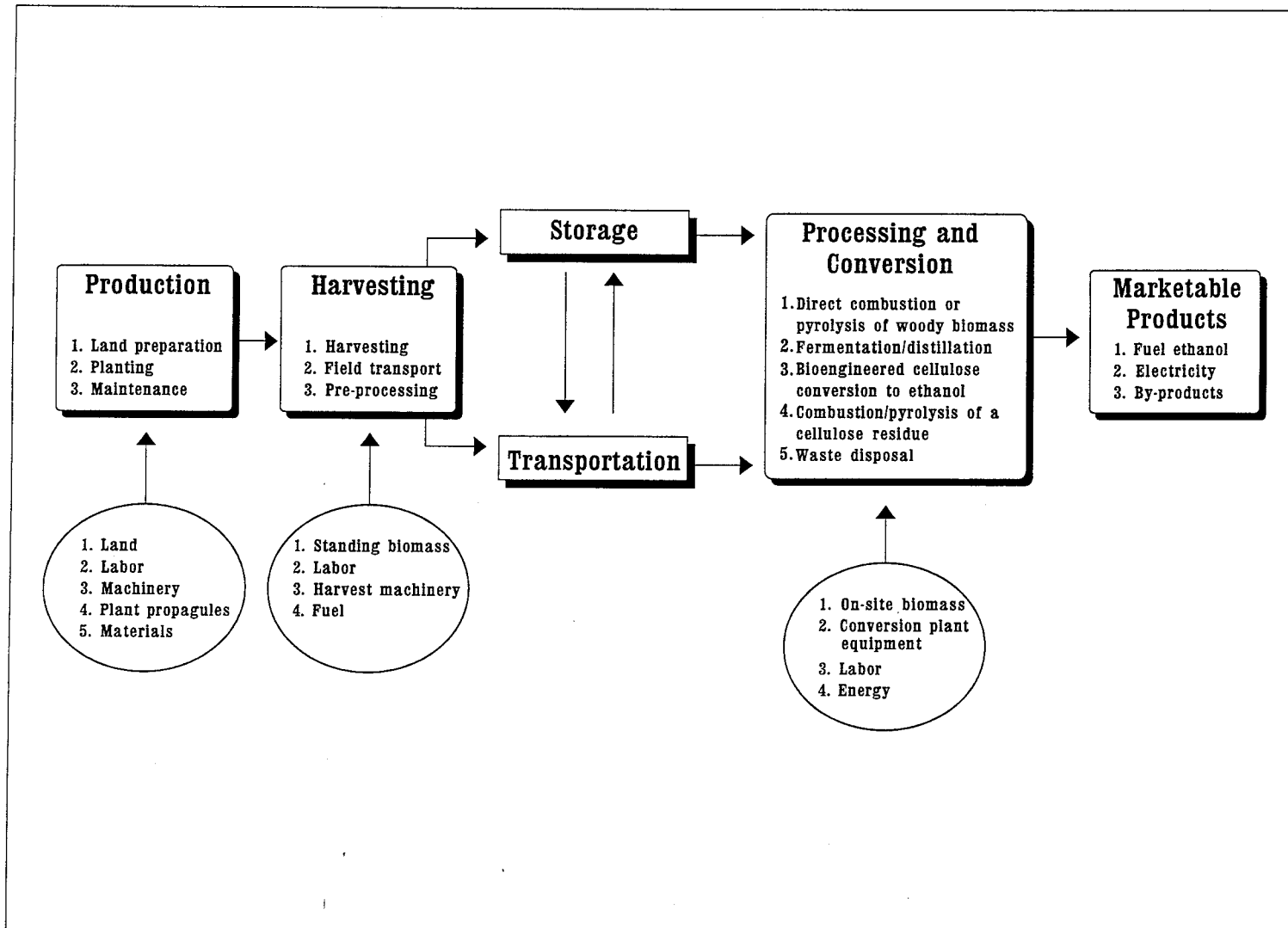


Figure 6-1. Integrated biomass system in central Florida

Table 6-1. Integrated Biomass Energy System Characteristics

Characteristics	Stage of System					Marketable Products
	Production	Harvesting	Transportation	Storage ¹	Processing and Conversion	
Activities	1. Land Preparation 2. Planting 3. Crop Maintenance (fertilization, pest control, irrigation)	1. Harvesting 2. Field transport 3. Pre-processing chipping (woody), baling, (herb.) pelletizing, drying	1. Transfer to vehicle 2. Road transport 3. Unloading 4. Retrieval from storage	1. Storage-in field or at plant (baled, bunched, piled, ensiled, etc)	1. Direct combustion or pyrolysis of woody biomass (sole source or co-fired) 2. Fermentation/distillation 3. Bioengineered cellulose conversion to ethanol 4. Combustion/pyrolysis of cellulose residue 5. Waste disposal	1. Electricity 2. Fuel Ethanol 3. By-products Demand for energy in Florida
Inputs (costs)	1. Land 2. Labor/management 3. Machinery 4. Plant propagules 5. Materials (fuel, parts, chemicals)	1. Standing biomass 2. Labor 3. Harvest machinery 4. Fuel	1. Harvested or stored biomass 2. Transport equipment 3. Fuel 4. Labor	Stored biomass	1. On-site biomass 2. Conversion plant equipment 3. Labor 4. Energy	Impact on personal & total income, value added, and employment
Outputs	Standing green biomass	Harvested biomass	Transported biomass	Stored biomass	1. Electricity 2. Ethanol 3. By-products (stillage, etc) 4. Waste products (ash, CO ₂)	
Issues and Environmental Aspects	1. Land availability, clay/other 2. Field accessibility (weather) 3. Plant material 4. Seasonal crop growth	1. Field accessibility, specialized machinery 2. Machinery cost and reliability 3. Seasonal crop maturation	1. Transportation capacity/cost 2. Traffic density	1. Crop storability 2. Storage capacity/cost	1. Seasonal availability of feedstocks 2. Cost for specialized plant equipment 3. Waste handling	

¹Storage may precede and/or follow transport of harvested biomass.

Potential Biomass Crops

There are three categories of potential biomass crops identified in Central Florida: herbaceous biomass crops consist of elephantgrass and forage sorghum; sugarcane and energycane are cane crops; and woody biomass crops include *Eucalyptus grandis*, *Eucalyptus camaldulensis*, *Eucalyptus tereticornis*, *Eucalyptus amplifolia*, Slash pine, and *Leucaena*.

Land Availability

Available lands for biomass production were classified by soil type and reclaimed and phosphate mined land reclamation status (Table 6-2). A total of 180,000 acres of mined phosphate land in Polk County can be considered as the major source of land available for biomass production. These acreages are mostly vacant and have a high fertility. Over 92,000 acres of phosphate mined land are clay settling areas and 88,000 acres are overburden. At the present time reclaimed phosphate mined lands consist of 44,000 acres of clay settling areas land and 72,000 as overburden land. Available land was estimated to be 37,000 acres clay settling (phosphatic clay) and 36,000 acres of overburden land. These acreages reflect adjustments for environmental reserves of 15 percent of clay settling areas and 50 percent of overburden, or for land more suited for other non-agricultural development (Project report by W.V. McConnell, November 1994).

Table 6-2. Available Lands by Soil Types

Land Types	Clay Settling (1000 acres)	Overburden (1000 acres)	Total (1000 acres)
All Mined Phosphate Lands	92	88	180
Reclaimed Phosphate Lands	44	72	116
Available Lands	37	36	73

If production of biomass crops becomes competitive and proves to be profitable in comparison to other crops grown in the area, 5000 to 10,000 acres of croplands may become available for biomass crop production.

Suitability of Biomass Crops to Soil Types

Based on information obtained from other subproject leaders, the potential available lands were categorized in three soil types, phosphatic clay, overburden, and croplands. The information indicated that phosphatic clay soils are highly suitable for all of the potential biomass crops, except *Eucalyptus grandis*, and pines (Table 6-3). Overburden soils and croplands are moderately suitable for sugarcane but highly suitable for other potential biomass crops.

Biomass Crop Yields

Biomass crop yields reflect factors including duration from establishment to harvest, freeze events, productive life of the crop and number of harvests per planting, as well as the inherent productivity of each crop-soil type in the central Florida area (Table 6-4).

On phosphatic clay land elephantgrass can yield up to 18, sugarcane up to 22, forage sorghum 11, and Leucaena 16 dry tons per acre. Yields on overburden soil or cropland are the same for elephantgrass and slightly lower for other biomass crops named above. Woody biomass crops will yield an average of 9 to 14 dry tons per acre annually on various soil types. For all *Eucalyptus* a 20 percent higher yield is expected on coppice regrowth.

Crop Activity Timetable

Seasonality in harvesting is an important issue for evaluating the performance of biomass energy systems, designing system capacity and evaluating the cost of storage. Because some activities are seasonally restricted due to limited field accessibility, and crops cannot be harvested throughout the year to provide input for a conversion plant, there are increased costs associated with these production systems. A **Crop Activity Timetable** was prepared for herbaceous and energy crops, eucalyptus species, and pines (Figures 6-2, 6-3, 6-4). These timetables show the windows for various agricultural practices and operations for each biomass crop.

Table 6-3. Suitability of Crop/Soils^a

CROPS	Soil Types		
	Phosphatic Clay	Overburden	Crop Land
Elephantgrass	1	1	1
Forage Sorghum	1	1	1
Sugarcane	1	2	2
Leucaena	1	1	1
E. grandis	3	1	1
E.camaldulensis/tereticornis	1	1	1
E. amplifolia	1	1	1
Pine	3	1	1

^a Suitability Class:

1-highly suitable

2-moderately suitable

3-unsuitable

Table 6-4. Biomass Crop Yields

CROPS	Years from establishment to harvest or harvest to harvest	Freeze interval expected (years)	Productive life per planting (years)	# Harvest per planting	Yield (Dry ton/acre per year by soil types)		
					Phosphatic clay	Overburden	Crop land
Elephantgrass	1	NA	6	6	18	18	18
Sugarcane ^a	1	(^b)	6	6	22	18	18
Forage Sorghum ^c	1	NA	1	1	11	10	10
Leucaena ^d	1	NA	10	10	16	15	12
<i>E. grandis</i> ^e	3	4	15	5	NA	14	13
<i>E. camaldulensis/tereticornis</i> ^e	5	8	15	3	9	9	9
<i>E. amplifolia</i> ^e	4	4	20	5	11	10	10
Pine	8	NA	8	1	NA	9	9

^a Productive life of 5 years on Overburden and Cropland.

^b Freeze risk only on sugar content.

^c Serious Pythium and nematode problems reported - yield data not included.

^d 2 years from establishment to first harvest.

^e Regrowth with 20% more yield. Yields should be decreased by 25% for seedlings.

As can be seen, elephantgrass, sugarcane, and leucaena have a harvesting window about 5 months. The harvesting window for woody biomass is much more extended, in some cases as long as 12 months. This advantage will result in minimal cost of storage. Wet field conditions during July and August may restrict field accessibility during this period. Considering special soil and weather conditions for growing forage sorghum, it seems that this crop faces some problems regarding planting and harvesting.

Some of the biomass crops, such as various *Eucalyptus*, may face a freeze risk. It was estimated that freeze damage decreases the yield for that particular year by as much as 50 percent.

Biomass Crop Cost Estimates

Various methods for estimating costs per dry ton of producing woody biomass crops in Central Florida were reviewed. A "levelized cost method" was selected to represent the stream of costs and benefits over a period of several years. The general idea of a levelized cost is to determine a constant-dollar value per unit of output, that if incurred over the life of project would yield the same discounted present value of costs as would the actual time-varying cost per unit of output. This method is often used by utilities for estimating fuel costs, and does not require an assumed discount or interest rate.

The total farmgate costs of production per dry ton for various woody biomass crops included land preparation, rent, establishment, maintenance, harvesting⁷, chipping, and forwarding within the field. Estimated farmgate costs for potential biomass crops were also compiled by soil type, planting practice (plantlets/cuttings or seedlings), and type of harvesting system (billet/hay or harvesting with forage chopper). Effects of freeze damages were also taken into consideration. To see the effect of changes in yields on total farmgate costs, a sensitivity analysis was performed (Tables 6-5a and 6-5b). Farmgate costs of production ranged from \$22 to \$29 per dry ton for elephantgrass, \$30 to \$48 for forage sorghum, \$21 to \$32 for sugarcane, and \$15 to \$43 for Leucaena. With no freeze risk consideration, farmgate costs for *Eucalyptus* ranged from \$29 to \$33 per dry ton. One dry ton of pine costs \$32 to be produced on overburden soil or cropland.

Freeze risk increases the farmgate costs for all *Eucalyptus* by 1 to 7 percent. Since cost of harvesting accounts for a considerable portion of farmgate costs, a 10 percent yield increase or decrease will not affect the cost of produced biomass notably.

Mined Lands and Energy Facility Location

A transportation analysis was performed for biomass produced in the mined lands area of central Florida, to estimate transport volumes (ton-miles) and transport costs (\$/dry ton) for the proposed biomass energy systems. Similar analyses reported in the literature have shown that transportation costs are often a limiting factor for biomass energy systems.

⁷ Harvesting and chipping or baling data for sugarcane, elephantgrass, and Leucaena were provided by another subproject leader, Jim Stricker; harvesting and chipping data for *Eucalyptus*, and Slash Pine were taken from; Rockwood, Donald L., N.N. Pathak, and P.C. Satapathy. "WOODY BIOMASS PRODUCTION SYSTEMS FOR FLORIDA", *Biomass and Bioenergy*, Vol. 5, No.1, 1993 (p.25).

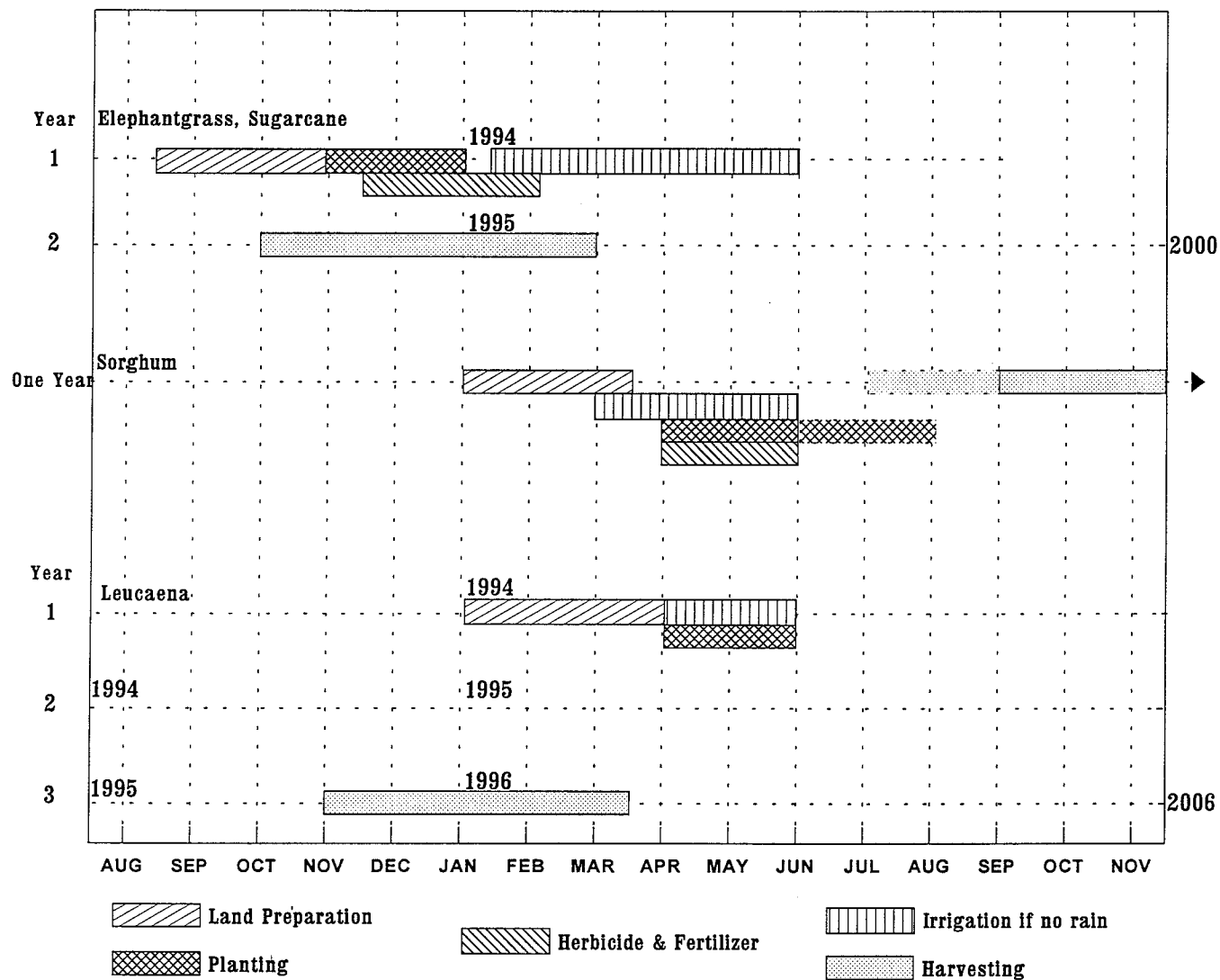


Figure 6-2. Crop activity timetable for sugarcane and herbaceous biomass crop

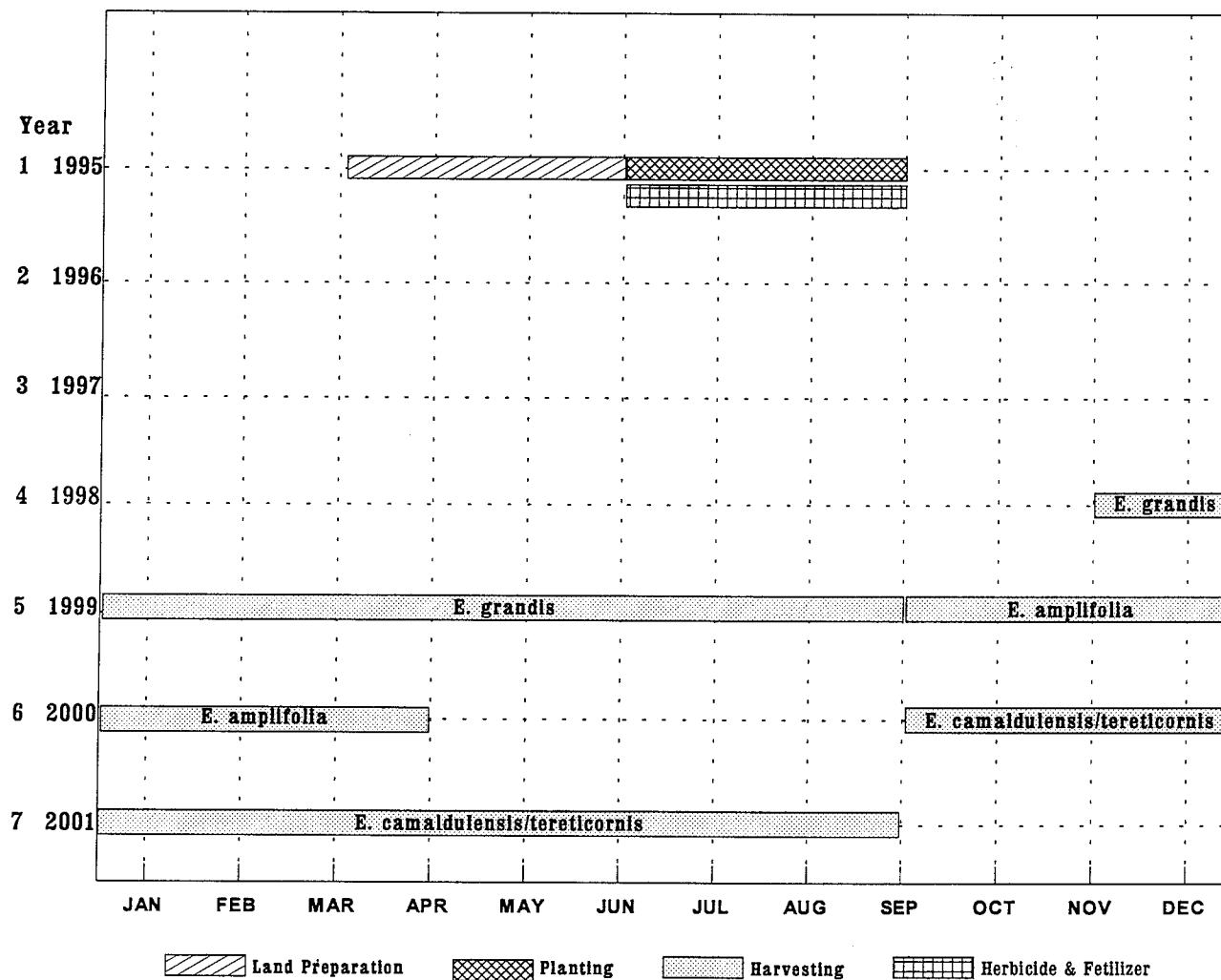


Figure 6-3. Crop activity timetable for *Eucalyptus* species

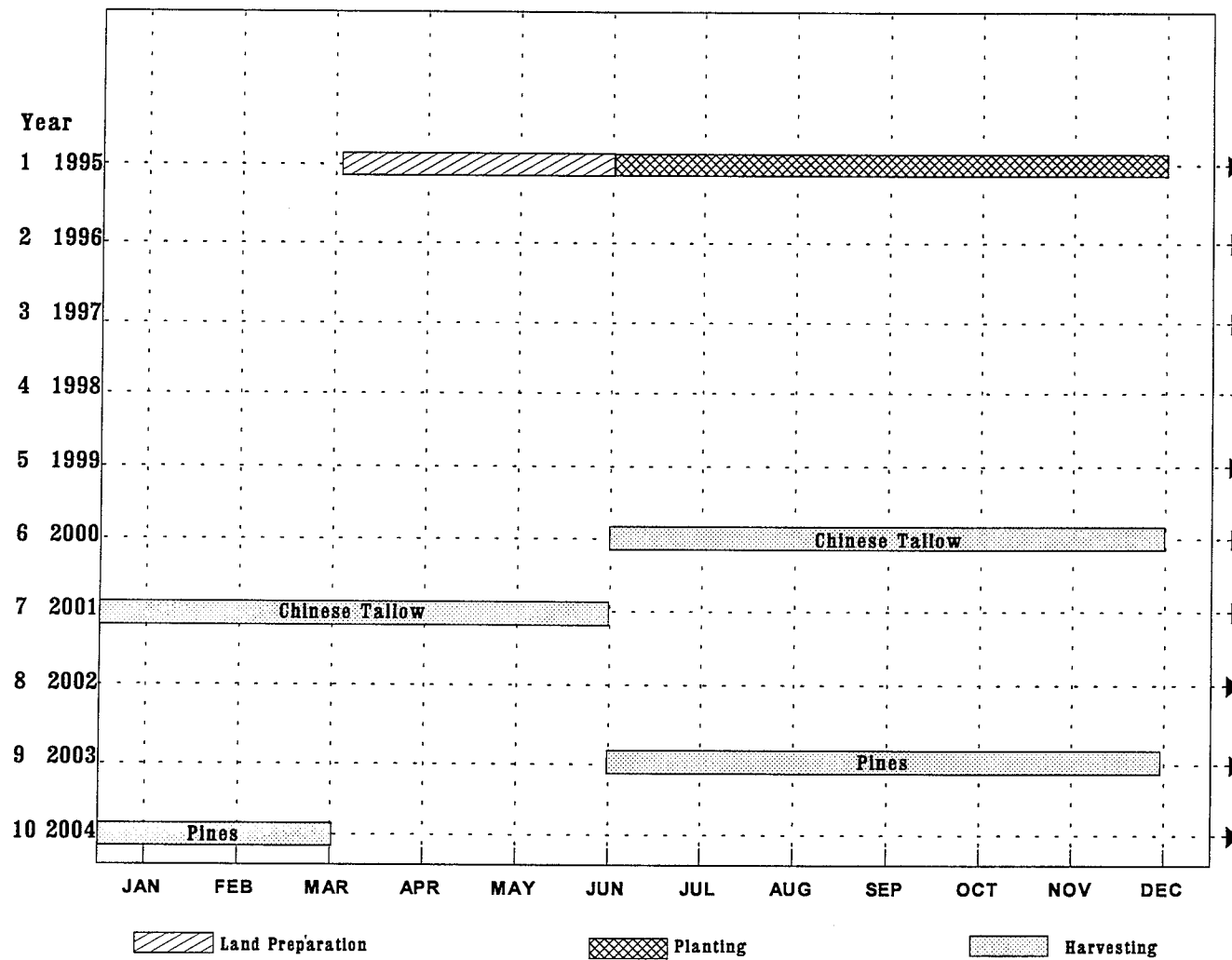


Figure 6-4. Crop activity timetable for chinese tallow and pines biomass crop

Table 6-5a. Biomass Crop Production/Harvest Cost Estimates Using Levelized Cost Method, by Soil Types and Planting Methods, Farmgate Costs for *Eucalyptus* and Pine.

Crops	Phosphatic Clay		Overburden		Cropland	
	Plantlets/ Cuttings	Seedling	Plantlets/ Cuttings	Seedling	Plantlets/ Cuttings	Seedling
-----\$/dry ton-----						
E.grandis		^a	28.79	29.22	29.33	29.78
With Freeze risk			29.57	30.04	30.17	30.08
10% yield increase			28.16	28.54	28.65	29.06
10% yield decrease			29.57	30.04	30.17	30.67
E.camaldulensis/tereticornis	32.67	33.32	32.67	33.32	32.37	32.93
With Freeze risk	33.45	35.63	34.93	35.63	34.61	31.92
10% yield increase	31.67	32.28	31.68	32.28	31.41	31.92
10% yield decrease	33.88	34.60	33.88	34.60	33.55	34.16
E.amplifolia	29.68	30.48	30.27	31.08	30.27	31.08
With freeze risk	31.19	32.04	31.81	32.67	31.81	32.67
10% yield increase	28.97	29.70	29.50	30.24	29.50	30.24
10% yield decrease	30.56	31.45	31.21	32.11	31.21	32.11
Pine				32.29		32.29
10% yield increase				31.34		31.34
10% yield decrease				33.45		33.45

^a Not applicable

Table 6-5b. Biomass Crop Production Cost Estimates Using Levelized Cost Method, by Soil Types and Harvesting Methods, Farmgate Costs for Herbaceous and Sugarcane Crops.

Crops	Phosphatic Clay		Overburden		Cropland	
	Harvesting Billet/Hay	Harvesting Forage Chopper	Harvesting Billet/Hay	Harvesting Forage Chopper	Harvesting Billet/Hay	Harvesting Forage Chopper
-----\$/dry ton-----						
Elephantgrass	27.21	22.15	28.64	23.58	28.88	23.82
10% yield increase	26.44	21.38	27.74	22.68	27.96	22.90
10% yield decrease	28.15	23.09	29.73	24.67	30.00	24.94
Forage Sorghum	37.50	29.77	47.95	38.24	45.50	35.79
10% yield increase	36.08	28.35	45.74	36.03	43.52	33.81
10% yield decrease	39.24	31.51	50.64	40.93	47.92	38.21
Sugarcane	28.47	20.64	31.46	23.60	31.70	23.84
10% yield increase	27.84	20.01	30.56	22.70	30.78	22.92
10% yield decrease	29.24	21.41	32.56	24.69	32.82	24.96
Leucaena	34.72	14.88	36.30	17.12	42.99	18.78
10% yield increase	34.45	14.61	35.85	16.67	42.39	18.18
10% yield decrease	35.05	15.21	36.86	17.68	43.72	19.51

Table 6-6. Mined Lands and Energy Facility Location - Polk, Hardee & Hillsborough Counties, Florida

Facility Type	Map Name	Distance to Plant (straight-line-mile)													
		Adjusted Acreage			Centroid Location		Nearest Plant								
		Total	Clay Settling	MOA	Lat	Long	ARK Energy	FPC	TECO Seminole	TECO	Ridge Gener.	ArKenol	Bartow Ethanol	Combust.	Ethanol
Mine	Big Four	1697	1377	320	27.72	82.01	19.8	14.9	8.2	6.3	26.4	19.9	21.9	6.3	19.9
Mine	Bonny Lake	4659	3862	797	27.91	81.33	7.8	7.0	18.6	13.8	9.8	7.3	8.0	7.0	7.3
Mine	Fort Green	6918	4648	2270	27.67	81.92	17.1	12.4	2.1	3.1	26.7	17.5	19.6	2.1	17.5
Mine	Fort Meade	4140	3052	1089	27.69	81.75	10.9	8.7	10.5	10.2	23.8	11.6	13.4	8.7	11.6
Mine	Four Corners	10459	7819	2640	27.64	82.05	24.6	19.7	8.7	10.1	32.2	24.9	26.9	8.7	24.9
Mine	Hardee	364	0	364	27.63	81.83	16.0	12.4	5.3	7.8	28.0	16.6	18.7	5.3	16.6
Mine	Hookers Prairie	2467	1538	929	27.73	81.84	10.6	6.1	7.5	4.6	21.4	11.1	13.2	4.6	11.1
Mine	Hopewell	3537	2971	567	27.91	82.01	17.8	14.8	19.4	14.7	16.8	17.4	18.5	14.7	17.4
Mine	Kingsford	11566	10118	1448	27.79	81.94	13.5	8.8	10.4	5.5	19.6	13.5	15.4	5.5	13.5
Mine	Lonesome	5652	5405	247	27.77	82.01	18.0	13.2	10.7	7.0	23.1	17.9	19.8	7.0	17.9
Mine	New Wales	263	0	263	27.83	81.94	13.6	9.3	12.7	7.8	18.1	13.4	15.1	7.8	13.4
Mine	Nichols	2837	2430	407	27.86	81.92	12.0	8.4	14.8	9.8	15.4	11.7	13.2	8.4	11.7
Mine	Norlyn Phosphate	9461	7852	1608	27.84	81.77	2.8	2.7	16.3	12.4	13.2	2.7	4.7	2.7	2.7
Mine	Payne Creek	8244	5343	2901	27.66	81.85	14.7	10.6	4.0	5.1	26.0	15.2	17.3	4.0	15.2
Mine	Peebledale	706	360	347	27.84	81.86	8.3	4.4	13.6	8.9	14.8	8.1	9.9	4.4	8.1
Mine	Rockland	4855	3972	883	27.74	81.76	7.7	5.1	11.3	9.2	20.3	8.3	10.3	5.1	8.3
Mine	Saddle Creek	7035	5088	1947	28.08	81.75	16.1	18.7	31.5	26.8	3.2	15.3	13.9	3.2	13.9
Mine	Silver City	2416	2003	413	27.78	81.81	6.7	2.1	11.5	7.9	17.6	7.1	9.2	2.1	7.1
Mine	Silver Springs	4048	3233	815	27.85	81.70	1.8	6.7	19.6	16.3	13.3	2.0	2.0	1.8	2.0
Mine	Watson	2203	1438	765	27.72	81.65	9.5	10.4	16.7	15.8	22.6	10.3	11.3	9.5	10.3
Mine	Hayesworth	na	na	na	27.75	81.94	14.5	9.6	7.6	2.9	22.0	14.7	16.7	2.9	14.7
Mine	CF Mining S.	na	na	na	27.57	81.85	20.6	16.9	6.1	10.6	32.4	21.2	23.3	6.1	21.2
Mine	Pasture	na	na	na	27.51	82.01	28.6	24.1	10.5	14.9	38.6	29.0	31.1	10.5	29.0
Mine	Wingate														
Combust. Plant	Arc Energy				27.85	81.72									
Combust. Plant	FPC				27.81	81.79									
Combust. Plant	TECO-Seminole				27.64	81.91									
Combust. Plant	TECO				27.72	81.91									
Combust. Plant	Ridge Generating				28.04	81.77									
Ethanol Plant	ArKenol				27.86	81.73									
Ethanol Plant	Bartow Ethanol				27.88	81.71									
Average							13.6	10.7	12.1	10.1	21.1	13.8	15.4	6.0	13.7

To estimate the cost of transporting biomass products to conversion plants, locations of phosphate mined areas and existing energy conversion plants were determined, using the project map of the Florida Phosphate Mining District provided by Mr. W.V. McConnell. The location of each facility was represented by a point visually placed at the centroid of the area. The map distance to each centroid point was measured latitudinally and longitudinally from a reference point. Then, these measurements were converted to absolute geographic coordinates, based upon the map scale and the geographic coordinates of the reference point. The straight-line distance was computed from each biomass production area (mine area centroid) to the nearest processing plants, as shown in Table 6-6. The average distances from fields in the mined area to plants ranged from 6 to 21 miles.

Based on information obtained and discussions with other subproject leaders having experience in this matter, transportation cost rates were estimated on an hourly basis because of the high fixed costs for this short-haul situation. Loading and unloading time dominated the transport operation. Transportation costs for biomass products were provided by Savant-Vincent Inc. Using a flat rate of \$50 per hour, and different vehicle types for biomass crops, transportation costs were estimated on a dry ton basis by adjusting for water content of green biomass. Based on moisture content and harvesting methods, transportation cost for various biomass feedstocks ranges from \$2.82 to \$11.16 per dry ton. Average cost of hauling about 500,000 tons of various biomass feedstocks to existing plants in the area was estimated at \$6.60 per dry ton.

Regional Biomass Supply Curve

In establishing regional biomass supply curves, average costs per ton were estimated for production levels ranging from 100,000 to 1 million dry tons of biomass feedstocks. A mix of crops was developed, based primarily on the following criteria: land availability, suitability of crop to soil types, harvesting time window, farmgate production and transportation costs, and environmental considerations. No increase in rent as a function of production volume has been taken into consideration. The basic assumption is that a producer will logically start with the most fertile land closest to conversion plants, the most suitable crops, and the highest yield crops. Based on all these assumptions, facts and projections, a combination of various biomass crops and the acreage of different soil types that can be utilized to produce various levels of biomass feedstocks in the area was conceptualized. A multiple biomass crop system will provide a longer harvesting window than a single crop system. This conceptualization reflects a feasible scenario. Other scenarios might be developed to optimize the crop mix, resulting in slightly lower overall costs. Two regional biomass supply curves were established, one based on farmgate cost of production only, and another one including transportation costs for products delivered to the plant. As Figure 6-5 shows, the average farmgate cost of producing one dry ton of biomass products in central Florida increases from \$25 at the yearly level of 100,000 tons, to \$27 for 1 million tons, due to utilization of less fertile soil and/ or including lower yield biomass crops in the production system at higher volumes of production. As it can be seen from Figure 6-5, transportation plus farmgate costs curve runs parallel to farmgate cost curve. This is because loading and unloading constitute the major portion of transportation cost in this short-haul situation, and therefore transportation costs was estimated on a per ton basis rather than per ton/mile basis.

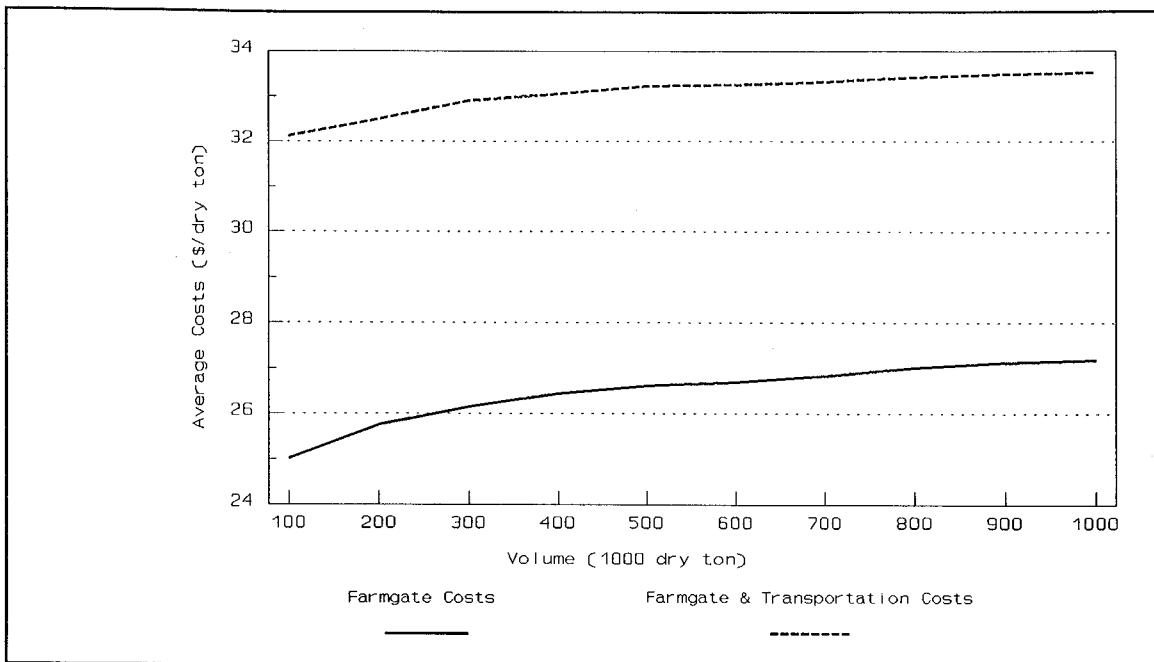


Figure 6-5. Regional supply curve for biomass products in Central Florida

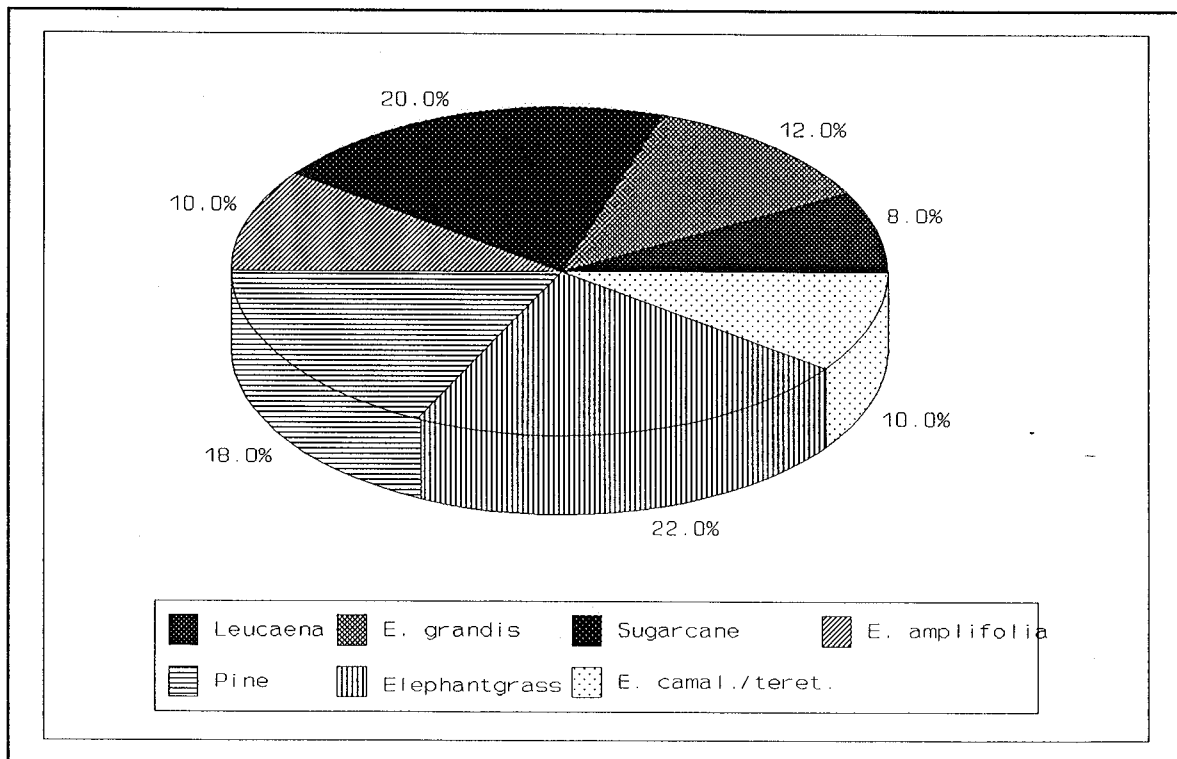


Figure 6-6. Biomass Crop combination for production of one million dry tons a year.

Figure 6-6 shows a possible biomass crop combination for production of 1 million dry tons in central Florida. A full capacity of 1 million dry tons was assumed to provide 500,000 dry tons biomass feedstocks for conversion to ethanol and 500,000 dry tons for conversion to electricity. Two potential crops have not been included in the biomass crop combination, Chinese tallow, due to environmental considerations, and forage sorghum, because of low yield and high costs relative to other alternative crops. Required land for production of one million ton feedstocks was estimated at 70,000 acres phosphatic clay and overburden, and about 10,000 acres of cropland.

7. *Future Markets for Ethanol and Electrical Power From Biomass in Florida*

Mohammad Rahmani, Alan Hodges, and Clyde Kiker⁸

Development of a biomass energy system in Central Florida depends primarily on a market for biomass products. Demand for biomass energy sources is mainly derived from demand for electrical power and fuel-grade ethanol. As part of this research project, information on the future markets for ethanol and electrical power in the United States and Florida were reviewed.

Biomass energy consumption in the U.S. in 1992 was estimated at 2.79×10^{12} Btu, with 81 percent from wood and the rest from solid waste and alcohol (U.S. Dept. of Energy, 1992). About half of this biomass energy consumption in 1992 was in the South (49%) and the other half in Northeast, Midwest, and Western United States. The industrial sector consumed 71 percent, the residential sector 29 percent, and electric utilities consumed less than 1 percent of wood energy in 1992. The southern United States had the highest share of wood energy consumption of 55 percent. Total U.S. consumption of energy from Municipal Solid Wastes combustion, manufacturing waste, and landfill gas in 1992 came to 457 trillion Btu.

U.S. consumption of ethanol in 1992 was 1,036 million gallons, or 79 trillion Btu. This was primarily used as an oxygenate supplement to gasoline automotive fuels. Overall 70 percent of U.S. consumption of ethanol in 1992 was in the Midwest where it is primarily produced from corn. Usage of reformulated gasoline is mandatory in some states of the Midwest. Ethanol demand expansion depends on its cost of production in comparison with the cost of gasoline and other blending agents. In general, without incentives ethanol cannot be competitive with petroleum as long as petroleum prices are below \$25 per barrel. Ethanol could be competitive, however, if credits for byproducts exceed the cost of corn (U.S. Dept. of Energy, 1992). "Consumption of ethanol in the United States as a gasoline supplement and octane enhancer is projected to increase to 130 trillion Btu by 2010", a 65 percent increase from 1992. This projection is primarily based on ethanol produced from corn.

Production of ethanol from other crops such as herbaceous biomass, sugarcane or even woody biomass is in the research stage. The results of various research activities on development of crops with high ethanol yields and improvement of conversion technology may allow that ethanol to be produced commercially. The results of over a decade of research in biomass crop production and conversion in Florida show that some high yield biomass crops can be utilized for conversion to ethanol or electric power. Our economic analysis shows that harvesting costs are a major component of total farmgate costs, so that even a ten percent increase in yield does not bring the total costs down significantly. More efficient harvesting machines are necessary in order for the costs of biomass crops to be competitive.

A study by Public Utility Research Center, at the University of Florida, (Sanford and Loungani, 1989) forecasting energy consumption in Florida from 1987 to 2006, suggests that total energy consumption will have an annual growth rate of 2.3 percent between 1991 to 1996, and 1.0

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percent annual growth rate between 1996 and 2006 for all energy using sectors. This study has taken into account population growth and economic activity, using historical data on consumption and prices. The growth encompasses all fuel types natural gas, coal, petroleum, electricity, and renewables, and includes residential, commercial, industrial and transportation sectors. The study also indicates that with the exception of renewables, the use of all fuels will grow modestly after 1991.

Another study (Electric and Gas Div., 1986) forecasts an average annual growth rate of 1.87 percent in winter peak demand by utilities and 1.67 percent in summer peak demand by utilities in Florida between 1996 to 2005. An average annual growth of 1.9 percent was shown for net energy use by utilities between 1996 and 2005 in Florida.

Energy consumption projections by the U.S. Department of Energy (Energy Information Administration, 1994) shows a total of 1.7 percent annual growth for primary energy consumption for the South Atlantic Census Division, during 1990 to 2010. Within this period, annual growth of electricity generated from renewable sources will be 2.3 percent, whereas the annual growth for electricity consumption for all sectors will be only 1.6 percent.

State energy data (U.S. Dept of Energy, 1994) for Florida show that while the total energy consumption from all sources has increased from 2,444 trillion Btu in 1980 to 3,066 in 1992, the increase has been very small for the last four years of this period, namely from 3,026 trillion Btu in 1989 to 3,066 in 1992. The main sources of energy consumed in Florida from 1983 to 1992 were coal, natural gas, petroleum, nuclear electric, hydro-electric power, and interstate flow of electricity. Petroleum with 1,577 trillion Btu, was the highest, and hydro-electric power with 2.4 trillion Btu was the lowest used source of energy in Florida in 1992. Coal, natural gas, and nuclear electric power also provided 652, 370, and 286 trillion Btu respectively of total energy used in Florida in 1992. Estimates of energy input at electric utilities within the ten year period, 1983-1992, show that coal, natural gas, petroleum, and nuclear electric power have been the dominant source for generating this kind of energy in Florida and electricity generated from biomass has not had a significant share.

Energy consumption estimates by sector in Florida show that transportation is the highest energy usage sector, followed by residential, commercial, and industrial sectors. Table 7-1 shows the energy consumption estimates by sectors from 1983 to 1992 in Florida. As this data indicates, commercial usage has had the highest growth within the ten year period, followed by residential, transportation and finally industrial energy usage sectors. However, the transportation sector has had the highest share with 36 percent, followed by residential sector with 27 percent, commercial sector with 23 percent, and industrial sector with 14 percent of total energy consumption in 1992.

The data indicate an overall growth of 28 percent in energy consumption in Florida for the past ten years, and this trend is expected to continue for the next ten years, assuming steady population growth and no drastic change in energy prices. To what degree biomass crops may contribute as a source of energy in the future, depends mainly their economic competitiveness. However, the environmental advantages of biomass crops may favor more usage of this source of energy in the future.

Table 7-1. Energy Consumption Estimates by Sectors, 1983-1992 in Florida

Year	Transportation	Residential	Commercial	Industrial	Total
-----Trillion BTU-----					
1983	938.2	586.0	460.7	403.8	2388.7
1984	927.2	611.2	487.7	432.9	2459.0
1985	951.2	664.2	559.6	435.4	2610.4
1986	1006.0	694.4	589.4	404.1	2693.9
1987	1060.5	721.3	612.5	398.8	2793.1
1988	1126.4	752.4	640.7	434.9	2954.4
1989	1141.7	790.7	667.1	426.6	3026.1
1990	1135.6	807.2	690.8	426.3	3059.9
1991	1074.1	823.7	699.6	420.7	3018.1
1992	1112.4	820.7	695.3	438.0	3066.4
Total growth 1983-92	18.5%	40.0%	50.9%	8.5%	28.4%

Source: "State Energy Data Report 1992, Consumption Estimates", U.S. Department of Energy, Energy Information Administration, May 1994.

The potential impacts of ethanol and electric power produced from 1 million tons of biomass feedstocks on the market for these commodities was estimated. One dry ton of sugarcane can be converted to 119 gallons of ethanol. The conversion ratio for elephantgrass was 101 gallons, Leucaena 100 gallons, and *Eucalyptus* 106 gallons per dry ton (Project report from Savant-Vincent, Inc. April, 1995). A combination of 500,000 dry tons of these biomass products can be converted to more than 54 million gallons of ethanol. Reformulated gasoline demand in the Lower Atlantic District for 1995 was projected at 123,000 barrels per day (Lidderdale, 1994) or 1.9×10^9 gallons a year. As a gasoline supplement and octane enhancer, ethanol can be substituted for 10 percent of the gasoline. Thus the ethanol demand projection as an additive to motor gasoline in the Lower Atlantic District would come to about 189 million gallons a year. Production of 54 million gallons of ethanol in Central Florida, which amounts to 29 percent of projected demand, would certainly affect the ethanol prices in the market.

Unlike ethanol, the electricity produced from 500,000 dry tons biomass feedstocks will have negligible effect in the market for electric power. Florida electricity consumption in 1992 was estimated at 82.7 billion kilowatt hours (Energy Information Admin, 1994). Based on the data obtained, 500,000 dry tons biomass products can be converted to about 629 million kilowatt hours of electricity. This represents only 0.76 percent of consumed electricity in Florida in 1992.

8. Socioeconomic Evaluation

Mohammad Rahmani, Alan Hodges, and Clyde Kiker⁹

Development of a biomass system in central Florida will have impacts on other sectors of the regional economy. The impacts will be in the form of added values for the final products, increased personal and total income, and higher employment in the area. To determine the scope of this impact, economic multipliers for Polk, Hillsborough, and Hardee counties were obtained from the IMPLAN input-out model (U.S. Dept of Commerce). The input-output multipliers consist of five tables: Personal Income, Output, Total Income, Value Added, and Employment Multipliers. Each table provides direct, indirect, induced, total, type I, and type III multipliers for more than 520 economic sectors. To estimate the potential impact of a biomass energy system in central Florida, a combination of biomass crops that will produce 500,000 dry tons were considered. The impacts of biomass crop production were calculated using the multipliers for "miscellaneous crops" and the value of produced crops at farmgate costs. Production of 500,000 dry tons of biomass feedstocks at farmgate costs, will generate over \$13 million in sales, \$22 million in total output, \$2.62 million personal income, more than \$10 million total income, and will add over 250 jobs to local payrolls (Table 8-1).

In addition, transportation services for hauling the feedstocks to conversion plants, and added value due to conversion of half a million dry tons biomass products to ethanol and electricity will generate additional output, income and jobs in the area. To estimate the additional impact of transportation, ethanol and electricity conversion, the multipliers for transportation services, industrial inorganic and organic chemical manufacturing, and electric services were used. These processes will have an additional value of \$3 million, \$15 million, and \$13 million, respectively. Table 8-1 shows the impact of these value-added services on total output, personal income, total income, and also employment.

Table 8-1. Biomass Crop Impact on Central Florida from Production of 500,000 Dry Tons

Economic Sectors	Value of Goods & Services	Total Output	Personal Income	Total Income	Employment
	-----\$ Million-----				# of Jobs
Misc. Crops	13.31	22.15	2.63	10.34	259
Transportation	3.31	5.33	2.16	3.03	104
Industrial Chem.	14.99	22.88	3.38	7.99	158
Electrical Serv.	13.53	15.98	2.54	7.83	87
Total	45.14	66.34	10.71	29.19	608

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Environmental Issues

9. Dedicated Feedstock Supply System

W.V. McConnell¹⁰

Introduction

The US Environmental Protection Agency (EPA) has identified commercialization of biomass production as a principle policy strategy for stabilizing global climate (Lashop and Tirpak, 1989). EPA's scenarios envision vast areas (e.g. 938 million acres) as being involved in such an effort. Workers in the emerging field of energy biomass management have realized that, without careful planning and implementation, the intensive management of such huge areas could create its own set of environmental problems.

At the same time, new concepts such as bio-diversity, sustainability, and ecosystem management at a landscape scale challenge the resource manager's traditional paradigms. This report is an initial effort to apply these concepts to the production of energy-biomass in intensively managed agronomic and silvicultural systems on reclaimed mined phosphate land in central Florida.

Methodology

A review of the literature and discussion with informed people revealed a set of environmental issues and concerns relating to the management of a Dedicated Feedstock Supply System (DFSS). Each environmental issue and concern was considered as it relates to reclaimed phosphate land in central Florida. Findings were consolidated, conclusions reached, and principles developed into a set of Best Management Practices (BMPs) applicable specifically to energy-producing reclaimed lands.

Issues and Concerns

Following is a list of identified issues and concerns in an approximate order of importance:

- * Sustainability/bio-diversity
- * Global climate (carbon cycle) impacts
- * Water and soil related impacts
- * Species selection, use of exotics
- * Site selection-coordination with other resources
- * Site management
- * Fuel haul to conversion facility
- * Wildlife, threatened and endangered species
- * Aesthetics

Common to all of the above is the need for public understanding and involvement.

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A report from the National Biofuels Roundtable dated May, 1994 *Principles and Guidelines for the Development of Biomass Energy Systems-Draft First Report*, discusses these, and other related issues, from the national perspective. Drawing on that report, this study examines the above issues as they relate to the proposed project.

Sustainability/bio-diversity

These intertwined concepts of fruitful permanence through the wise management of diverse natural systems are really at the heart of this project. All of the actions proposed are directed towards these twin ends. Phosphate, whose production resulted in the existing land condition, is non-renewable. The regional economy that it supports and the far-flung agronomic systems that depend on it are not sustainable in their present form. The challenge is to renew the land's productivity so as to best serve the long-term needs of humanity as a part of the total environment. Energy production is but one of these needs. For this reason, this study will consider energy biomass production within the larger framework of regional landscape-scale planning.

The Florida Department of Environmental Protection's (DEP) Bureau of Mine Reclamation (BMR) is acting as the lead agency in formulating a nine-county district reclamation plan which recognizes the natural, economic and political considerations of the future. This plan, *A Regional Conceptual Reclamation Plan for the Southern Phosphate District of Florida* (hereafter called the "District Plan") is expected to serve as the nucleus for a comprehensive regional landscape plan. The District Plan and the supporting *Guidelines for the Reclamation, Management and Disposition of Lands within the Southern Phosphate District of Florida* (Cates and Zippay, [draft] 1993 (hereafter call "District Guidelines")) are the master documents which will guide the planning for renewable energy production in Polk County. Excerpts from the District Guidelines join with DFSS-specific guidelines to constitute the Best Management Practices as they appear later in this report.

The issue of sustainability cannot be isolated from the all-determining matter of human population. At the current rate of increase, earth's population of 5.7 billion will double in 40 years, a density considered by most authorities to far exceed the planet's human carrying capacity. Sustainability of any microsystems such as a Dedicated Feedstock Supply System, can be achieved only as it is part of a suitable global macrosystem. All of the actions taken under this, or any other, resource management program will have no meaning-global macrosystem sustainability cannot be achieved-without population stabilization.

Global climate change.

The 73,000 acres of energy farms conjectured in *Land Availability and Value - Central Florida Reclaimed Phosphate Lands* (Section 1 of this report) will produce 1,300,000 dry tons per year of biomass. Its use to replace fossil fuels will result in a net reduction in carbon emissions of some 600,000 tons annually.

Water and Soil.

Rapid population growth and resulting water shortages in central and south Florida foretell an escalating series of inter- and intra-regional battles over water rights. The relative water

requirements of alternative energy production modes may be a deciding factor in choosing the preferred option. Biomass production planning will consider the need to protect water quality and to minimize water consumption.

Elephantgrass, sugarcane and leucaena will benefit from supplemental irrigation at planting time, when there is not sufficient natural rainfall. Such irrigation will reduce the risk of a significant economic loss resulting from crop failure along with the loss of land use for one season. This risk will vary by landform and species and may be partially quantified through long-term (el Niño related) weather forecasting. A risk analysis to determine the economics of installing an irrigation system *vis a vis* reliance on natural rainfall is beyond the scope of this paper but should be considered as this program advances to its second phase and considers individual projects. Once established, these crops require no additional supplemental irrigation over the 6 to 10 year life of the stand. Sorghum will likely require supplemental irrigation annually as it must be reestablished annually and normally will be planted during the dry season.

While the wastewater problems associated with ethanol production are addressed in section 10 of this report (Processing/Conversion associated impacts), it should be mentioned here that wastewater from biomass ethanol production can potentially offset some of the irrigation requirements of agronomic systems. These production wastes include stillage, evaporator condensate, anhydrous processing wastewater and boiler blowdown. Some of these waste-streams may require treatment prior to land application in order to avoid the possibility of temporary nitrogen immobilization and/or salinity effects which could lead to crop damage. While nutrient levels in the waste-streams may be low, returning these nutrients to the cropping system is the only means to achieve fully sustainable production. The logistics, economic feasibility and environmental impacts of transporting the wastewater to and distributing it at the farm will depend primarily on plant location/design and on the design of the energy farm supporting that specific facility. Such determinations are beyond the scope of this report but must be made, along with consideration of alternatives if recycling is not feasible, should this project progress to the next level and involve ethanol production.

The disturbed soils produced by mine reclamation are more productive for agricultural crops than the native soils that they replace. We conjecture that 37,000 acres of highly productive clay settling areas will be the mainstay of energy-fuel production, with another 36,000 acres of less fertile mined-out lands, also in production. Maintenance of soil productivity is a major concern in planning. Soil amendments, such as composted sewage sludge and recycled non-toxic ash from combustor-generators, could play an important role in maintaining fertility and improving water-holding capacity. the use of sewage effluent for irrigation and fertilization is a possibility for those lands located near treatment facilities.

Waste application will be done at agronomic rates in accordance with standards established in USEPA publication 625-83-016 *Process Design Manual for Land Application of Municipal Sludge* and with other applicable standards established by USEPA and the Florida DEP.

Elephantgrass and sugarcane have the ability to recycle nitrogen from the lower leaves to the upper part of the plant during the growth cycle. As a result yield in excess of 20 dry tons per acre are possible with nitrogen fertilization rates of 120 lbs. of N per year on phosphatic clay and 150 lbs. per year on sandy soils. Leucaena, a legume, requires no supplemental nitrogen.

With the exception of sorghum, the potential for erosion in the management of energy crops is substantially less than for conventional agricultural crops. The 6 to 20 year interval between establishments greatly reduces tillage and the opportunity for soil erosion. The extended harvest interval for trees means that machinery will not be entering the fields for periods of 3 to 8 years, minimizing soil compaction and allowing properly positioned tree stands to act as run-off filters for the adjacent field crops. Sorghum, needing annual re-establishment, approximates conventional field crops in its erosion potential.

Species selection.

Species choice will, of course, depend primarily on the species usability for the product and within the process selected. Within this usability range a number of alternatives exist.

Agronomic research on reclaimed mined land has identified a variety of species as suitable for energy-fuel production. With the exception of slash pine (*Pinus elliottii*), and sand pine (*pinus clausa*) all of the most productive species are non-native. The use of non-native species in an agricultural cropping system is not undesirable, recall that most field crops grown in this country are non-native. The principal species proposed for use, elephantgrass (*Pennisetum purpureum*), energycane (*Saccharum sp*), leucaena (*Leucaena sp*), and *Eucalyptus* (*Eucalyptus sp*), are considered to have low invasive potential in the central Florida DFSS context. A top producing candidate, Chinese tallow (*Sapium sebiferum*), is considered invasive and will not be used.

At the present state of the art, grasses and canes can be established only by cuttings. This process is quite expensive (\$500+ per acre) compared with seeding (<\$200 per acre). Their limited persistence (6 years) and nitrogen requirements must be considered in the choice of species. Additionally, the end use and attendant harvesting/processing protocol (grasses can be solar dried, energy canes cannot) will influence species choice.

The issue of sustainability (energy input) argues for the use of legumes to eliminate the need for nitrogenous soil amendments. Leucaena, a high producer which can be established from seed at low cost, is a legume. These attributes, together with the species persistence (10-20 years) under coppicing make it a preferred species. *Eucalyptus*, with their high yield, coppicing ability, long life and ability to withstand summer harvesting (for *E. amplifolia* and *camaldulensis*) are the preferred tree species.

Site selection.

Core lands for energy production are clay settling areas (CSAs); lands eminently suited for crop production. These large (200-2,000 acres) blocks present a challenge in maintaining biodiversity, not only from an ecological standpoint but also because of the economic risks (disease and insect) inherent in extensive monocultural systems.

Mined out areas (MOAs), while less fertile, are more versatile than CSAs. MOAs are usable for pasture or row-crops, citrus or timber production, residential, industrial, recreational and commercial uses. They are also the lands that must serve as wildlife habitat and water recharge areas. Use of these lands will depend on the landowners wishes, determined for the most part by economics. Our early and highly speculative estimate is that about 50% of the total MOA area will be available for energy crop production.

In all cases, area allocation and site planning must be done with the full cooperation of the landowner and reflect his long-term goals.

Site Management

Energy crop production will use standard or slightly modified agricultural or silvicultural practices. Guidelines for management appear later in this report under the section titled "DFSS Best Management Practices".

Fuel Haul to Conversion Facility

A major public concern with any industrial development is the possibility of traffic congestion and road deterioration. For bio-energy installations, plant location and plant capacity are the key determinant of the impacts resulting from fuel hauling. In a best case scenario, where the plant is located in the center of the DFSS, and all transportation is by farm wagon, no social impacts will result and economic costs will be minimal. A worst case scenario might involve hauling 150,000 tons of green material per year (30+ loads per working day) over low standard/high use roads and through residential areas. Use of these guidelines will minimize hauling impacts:

- * Locate plant (select farm areas) so as to minimize haul distance and to avoid transport through urbanized areas. This makes sense both economically and from a public acceptance standpoint.
- * Optimize the size of the conversion facility, balancing haul costs (both social and economic) against economies of scale.
- * Design farm (select species) and schedule harvest to disperse cut over time.
- * Store stockpiled fuel at the farm rather than at the plant site.
- * Route haul traffic to avoid low standard, high use roads and residential areas.
- * Where feasible, provide for night and weekend deliveries to disperse traffic over time.

Wildlife, Threatened, and Endangered Species

A number of threatened and endangered species use the area under consideration. There is no indication that biomass production would aggravate critical habitat for them on reclaimed lands targeted for energy crop production. Species include wood stork, peregrin falcon, and bald eagle. Landscape design of a DFSS would help provide landscape diversity and an abundance of diverse species.

Plant species preferred for energy-biomass production are exotics and have no wildlife forage value (*Leucaena* may be browsed by deer). The dense canopy of the managed stands will allow no sunlight to reach the ground within the stands themselves and production of food producing weeds, grasses, and shrubs will be minimal. However, access roads, stand boundaries, and especially edges of watercourses, wetlands, greenways and natural areas offer opportunities for establishment and maintenance of wildlife-friendly areas. As will be discussed later under **DFSS Best Management Practices**, the design team for the DFSS should include a wildlife biologist

or ecologist whose responsibilities will include planning for food plots, open areas, and nesting and escape cover.

Aesthetics

Conversion of the existing "moon-scape" to a well-ordered pastoral scene created with consideration of all of the issues and concerns noted above will constitute an aesthetic renaissance for the area. While the geometry of drainage of clay settling will not usually permit curvilinear design, the dispersion of stands and species on this landform will enhance both diversity and esthetics. Mined out lands and native soils offer a wide array of options in stand design with stand boundaries conforming to and emphasizing topography. The illustrations on the cover and on page 8 of *The American Farm* (NREL/SP-420-5877 March 1994) suggest opportunities exist to combine utility with beauty.

Harvesting of trees for biofuel will differ in method and context from conventional forest products harvesting. Total utilization will result in a clean forest floor and regeneration though coppice will be immediate. The stands themselves will be part of highly publicized and intensively managed agricultural system in which the viewer will expect to see crop harvesting. In this system the removal of trees should be as acceptable to the public as is a wheat or corn harvest and we expect that no specific measures to modify harvesting activity will be needed.

Public Involvement and understanding

A common thread joining all of the just-discussed issues and concerns is the human element. The social and economic impacts of closed-loop renewable energy production are the subject of another task. Absolutely essential to the success of the proposed project is the involvement of the concerned public. The preparation of the environmental plan for this project and its successful implementation will require the understanding and support of the environmental community, concerned public agencies, legislators, landowners and individuals.

DFSS Best Management Practices

Energy-crop producing lands are included in the set of lands designated as the "Coordinated Development Area" (CDA). The land set, together with its prescribed management and alternative final land disposition is described in Section 3.0, 4.0 and 5.0 of the District Guidelines. The management directives given in Guidelines, Section 4.0, together with energy-crop specific policy statements constitute the DFSS Best Management Practices for energy crop production on reclaimed phosphate lands in Polk County.

I. Selecting, designing and managing DFSS sites involves not only the site itself but also the total regional landscape. Such decision-making can best be done by an inter-disciplinary (I.D.) team. Depending on site characteristics and management objectives, this team might consist of some combination of:

- * Landowner/grower-manager
- * An agronomist
- * A forester
- * An agricultural-engineering technician
- * A generalist/ecologist/environmental specialist

Review of the site plan by a representative of local government will ensure consideration of socio-political concerns.

II. The design team will conform all elements of DFSS development to the following general guidelines from the District Guidelines, Sec. 4:

Silviculture - All tree plantations should be planted "on the contour". The terminology translates that all tree rows should be planted parallel to the topographic contours rather than across contours (rows planted across, rather than up and down slopes). Planting on the contour will control erosion and runoff velocity; and will aid in nutrient absorption. In some cases, normal commercial spacing may need to be varied to facilitate mechanical control of exotic/nuisance plant species. Prescribed burning will reduce competition, facilitate nutrient release, and aid in control of exotic/nuisance species. Prescribed burning should be accomplished once plantations have reached the appropriate age/condition class. Locating silvicultural plantations adjacent to the Integrated Habitat Network (IHN), to serve as buffers, is generally encouraged. However, plantations of non-indigenous trees should be planted as far as possible from the IHN and interconnecting watercourses. The use of "Agro-forestry" silvicultural practices is also encouraged, where appropriate. Agro-forestry concepts employ varied tree spacing in combination with alternating strips of pasture grasses (native or non-native) and/or wildlife food plantings. Agro-forestry applications are flexible according to site, intended use or needs, and may be considered as adjunct wildlife habitat.

Agronomics/row Crops - From previous experience it is known that a variety of agronomic crops can and may be grown on all landforms of the CDA. The possible exceptions being areas of deep sand tailings or inappropriate topography. Agronomic croplands and citrus groves provide the highest potential for the creation of turbid runoff, excessive nutrients, and pesticide contamination. It is paramount that all croplands strive to incorporate the most-up-to-date practices of the general concept known as *Sustainable Agriculture*. Research into applications of this concept is currently being performed by the University of Florida, Institute of Food and Agricultural Sciences at such proximal sites as the Polk County Mined Lands Agricultural Research/Demonstration Project, Lake Alfred Citrus Experiment Station, Ona Agricultural Research and Education Center, and Buck Island Ranch (Lake Placid). The concept of sustainable agriculture is basically to reduce input (cultivation, ergo fuel consumption, fertilizer, and pesticides) while maintaining a high level of production and economic return. When combined with the similar practices of BMPs and non-point source pollution control, a production and management system can be devised which minimizes environmental damage.

Management for agricultural sites will also follow the detailed practices found in *Guide for Determining Agricultural Best Management Practices*, USDA SCS, and US Environmental Protection Agency, 1997 and, more specifically, in *USDA SCS TECHNICAL GUIDE, SEC. IV*.

Where trees are the energy crop, management will follow the guidelines contained in *Silvicultural Best Management Practices - 1993*, Florida Department of Agricultural and Consumer Services, Division of Forestry.

III. Supplement these silvicultural and row crop practices with the following DFSS specific guides.

- a. As a guide, maintain stand size (areas of same species grasses or trees) between 40 and 200 acres, favoring stands of less than 100 acres.
- b. Favor low energy-requirement (on a life-cycle basis) species.
- c. On MOAs, silvo-pastoral systems may offer increased returns to the landowner with only a modest reduction in energy production. Consider combinations of pine and/or *Eucalyptus* with pasture grasses.
- d. Shape and position stands and design stand structure to enhance aesthetics.

"Because the art/science of reclamation is adolescent and unique, the guidelines for postreclamation management --- will necessarily evolve with application" District Guidelines, Sec. 1.0

Conceptual DFSS Site Plan

This plan (appendix G) covers a portion of a central Florida mine as shown on Map A. Map B illustrates possible crop layout aimed at electricity production and conforming to BMPs. Actual site design of this area would require on-the-ground inspection by the I.D. team, with consideration of access (transportation system), drainage and site variations, water quality (stream crossing and buffering), and "natural area" treatment. These and other management constraints and opportunities are not discernable without on-site inspection.

Environmental Issues Related to DFSS - Meeting

A meeting was held in Bartow on March 1, 1995 to discuss environmental issues as they relate to establishment of extensive plantings of biomass materials for conversion to energy. The minutes from that meeting follow.

Introductions:

Mr. Jim Stricker opened the meeting at 10:00 a.m. by having all attendees introduce themselves and indicate their affiliation.

In Attendance were:

Wayne Smith, University of Florida; Tom Pospichal, Cargill Fertilizer; Sam Tice, local businessman; Jim Leary, University of Florida; Gerald Tice, Farmer; Chris Stone, Central Florida Regional Planning Council; Jim Everett, Fairview Farms; Charles Saddler, and Mike Mahler, Polk County Environmental Management Dept.; Steve Richardson, Florida Institute of Phosphate Research; Ed Sheehan, USDA-NRCS; Paddy Rice, IMC-Agrico Co.; John Ryan, League of Env. Organizations; Phil Tuohy, Wheelabrator Ridge Generating Station; Jim Kelley, Mobil Mining and Minerals Co.; Wayne Hoffman, National Audubon Society; Gordon M. Prine, University of Florida; Don Rockwood, University of Florida; Jim Stricker, Polk County Extension Service.

Rationale for Dedicated Feedstock Supply System & NREL Project--Wayne Smith

During the mid-1970s, Oak Ridge National Laboratory directed an initiative in biomass crop development. In Florida, the Center for Biomass Programs was established at the University of Florida and conducted a contributing project. The Center also received supplemental funds from the Gas Research Institute to conduct a greatly expanded program. The issues of the day were agricultural over-production and energy supply uncertainty. Use of agricultural lands to support biomass for energy could address these issues. The use of biomass was viewed as a way to supplement the energy required in the state especially with 85% of the energy imported. And now, with concern for the environment and CO₂ emission/unit of energy, biomass continues to be seen as part of the solution.

Several plant resources are available. Some 400 species have been evaluated in Florida. Conventional food crops have been ruled out. The energy balance for food crops is poor. Sugar production from Sugarcane, for example, has an energy output of 5.95 units for every 1.24 units of input (or 4.8 to 1). For energy crops, a ratio of 10 to 1 or better is expected. The technology of primary interest for biomass-to-energy conversion is that which either produces electricity or alcohol fuels.

Why project is located in central Florida--Jim Stricker

In order to support an energy crop the land must be available. Polk County has approximately 1.3 million acres of land. Of this, 611,000 acres (47%) is farm land, 225,000 acres (17%) is mined for phosphate, 92,000 acres (7.1%) are for clay settling of which 37,000 acres are potentially available for biomass. In addition, 88,000 acres of improved pasture land and 210,000 acres of unimproved pasture land; some of which could become available. The biomass energy crop development program noted above identified species showing great promise for the soils in the central Florida region.

Targeted species - tree crops--Don Rockwood

Eucalyptus and other species have been evaluated as a viable energy crop for south and central Florida. *Eucalyptus* are well-suited for the clay settling and overburden acres. They are fast growing and have good harvest-ability. Their presence in Florida for several decades have shown them to be non-invasive. Pine and other native species can be grown, but their yields are much less.

Q(John Ryan): Are there any multiple-use sites which grow both energy and food crops for example, or energy and paper/pulp crops? Or is this an "intensive culture"?

A(DR): We will structure the "intensity" to grow species which can be harvested in the short run for energy or let them grow (8-10 years) to diameters from 8 to 10 inches for use in paper/pulp products.

Comment (Ryan): What is needed are bank/loan entities that will "carry paper" on a ten year basis.

Comment (DR): Another advantage (multiple-use) of eucalyptus is as a replacement for cypress mulch.

Targeted species - tall grasses (elephantgrass and sugarcane) and leucaena--Gordon Prine

These species have yielded 25 tons of dry matter/acre. The canes and elephantgrass require vegetative propagation. A full-sized John Deere chopper is too small to do a good job harvesting the grasses, however, a bigger unit manufactured in Sweden may meet the task.

Leucaena can be planted from seed but the tall grasses are planted vegetatively from stem pieces. Leucaena can be used as an annual, woody biomass crop or grown 2 or more years as a short rotation woody crop where winter allows.

Comment (Wayne Hoffman): Leucaena is considered a pest in the Florida Keys. It may not be a problem this far north. Wayne also spoke of the need for a contractual agreement between both the power producer and the energy crop supplier (grower) to ensure that the 1) the supply of biomass is assured and 2) the grower can expect a fair return on investment.

Conversion options being evaluated--Jim Stricker

Four production/conversion systems are being considered. They consist of the following:

1. Ferment juice from sugarcane to ethanol, presscake to methane gas or convert to cattle feed.
 - Use a Claas-type harvester to chop and blow into a trailer.
 - Harvest with billets, 20 to 24 inches in length
2. Direct combustion of elephantgrass, leucaena or *Eucalyptus*.
 - Cut and store. Use as needed.
3. Ferment juice from sugarcane, convert cellulosic materials in presscake to ethanol.
4. Convert whole plant sugarcane, elephantgrass, *Eucalyptus*, or leucaena directly to ethanol.

Environmental issues/discussion--Wayne Smith moderated group discussion

Wayne Smith distributed an list of environmental issues of concern. He also addressed efforts to use the waste stream from ethanol to produce biogas and recycling of waste water from this process and ash from combustion back to production sites.

Comment (John Ryan): Stated that there exists a problem with any monoculture. Sees that the solution is multiple use and multiple supply from the land. He also said, "You are in a position to influence, by recommendation, a market, or develop an industry." He mentioned concern over not using the rail system. He believes there is a need to support the rail system. Additionally the project should help "stabilize the economy and create multiple use cultures (not monocultures) which help stabilize/maintain the environment and allow for 'agriculturalist' to include additional uses of crops beyond only biomass-for-fuel."

Comment (Wayne Hoffman): In general support for biomass but has concerns for the support of wildlife. *Eucalyptus* plantations, for example, will likely support less wildlife habitat than if left

fallow. Look into habitat value of other species of energy crops. *Eucalyptus* has a chemical which makes it unfavorable to almost all wildlife. Poplar species are good for wildlife habitats.

Request to WH (Wayne Smith): From your references/resources, would you supply us with information on the effect of *Eucalyptus* on wildlife habitat.

Reply (WH): Yes.

Discussion (Group): Considerable discussion focused on the targeted species being non-native. In the targeted region, it is believed that the biomass species will be similar to the over 50 non-native species in domestic crop production. Also, it was noted that there are threatened species that use the area, although there was no indication that biomass production would aggravate critical habitat for them (e.g., wood stork, peregrin falcon, and eagle). Landscape design will provide landscape diversity and an abundance of diverse species.

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10. Processing and Conversion of Biofuels

W.V. McConnell and Ann C. Wilkie¹¹

Introduction

The environmental impacts associated with the growing, harvesting and transportation of biomass feedstocks in the NREL Polk County Project are discussed in report 9 *Dedicated Feedstock Supply System*. This report will qualitatively address the problems associated with the processing of these feedstocks and converting them to energy. The NREL project envisions two principal alternatives: production of electrical energy and production of liquid fuels. Facilities for these production processors are heavily regulated by state and federal agencies and the permitting process, which differs for each, is lengthy and complex. Should the NREL project progress to the next level, identifying individual projects and determining their feasibility, the specific problems of the selected process at the chosen site will be addressed at that time.

Principle Non-specific Impacts

The Florida Power Plant Siting Act, as amended (403.501-517, F.S.) and implemented by 17-17 requires consideration and discussion of an extensive array of impacts associated with the construction and operation of power generating facilities. The Table of Contents for the *Instruction Guide for Certification Applications (DER Form 17-2.211(1))*, lists these impacts and is shown in appendix G. The reader will note that the application considers not only the plant, site and vicinity but also the construction of any serving transmission lines and other linear facilities such as roads, rail lines and influent or effluent pipelines. The state Power Plant Siting Officer estimates that preparation of this application will take 1 1/2 years and processing a similar time period. Construction of the Ridge Generating Station which came on-line in 1994 in Polk County required some 22 individual permits. No such single point application form is available for the construction and operation of ethanol plants but equivalent requirements exist and covering permits must be obtained from appropriate state and federal agencies.

This study makes no attempt to quantify the non-specific impacts of processing and conversion which will be required under existing laws and regulations.

Project Specific Impacts

This report will consider 2 project-specific impacts: (1) disposal of wastewater from ethanol production using enzymatic or acid hydrolysis from biomass feedstocks and (2) environmental impacts of combusting biofuels containing ²²⁶Ra, an element found in all plant material but in greater quantities on plants grown on reclaimed mined phosphate lands.

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Ethanol Production: Wastewater Processing/Conversion and Disposal

Abstract

An evaluation of anaerobic digestion and by-product recovery in the biomass to fuel ethanol industry was performed through a review of technical literature and solicitation of related expertise with a goal of seeking solutions pertinent to a dedicated biomass feedstock supply and conversion to ethanol system using reclaimed phosphate mine-lands of central Florida. This effort has resulted in a substantial bibliography which supports the viability of anaerobic digestion for stillage treatment followed by land application on biomass crops for nutrient recovery. Other supporting processes for stillage utilization and by-product recovery considered worthy of continued investigation include the production of feed (from single cell protein and/or algae production) and the recovery of organic chemicals of industrial significance. This evaluation also discloses some risks in implementation of this technology prior to exploring some areas where knowledge appears to be lacking. Specifically, the data on biomass hydrolysis stillage is extremely limited and highly variable and this has significant impacts on the capital costs and biogas recovery predicted from this data. In addition, some technical questions remain unanswered in regards to stillage toxicity from untested feedstocks, effluent phytotoxicity when applied to standing crops, the long-term impact of Na salts in the effluent on agronomic properties of phosphatic clays unique to central Florida, and the impact of heavy metal leaching when acid hydrolysis reactors are fabricated from corrosion resistant alloys. The results and conclusions suggest that sustainable and economically viable solutions for mitigating environmental problems which result from large scale biomass to ethanol conversion facilities are available, but implementation of suitable solutions incurs some risk due to some remaining questions which are worthy of investigation.

Summary (Full report presented in Appendix H)

Objective - As an enhancement to the principal project of determining economic and technical feasibility of a biomass energy dedicated feedstock supply system centered on phosphatic clay soils resulting from mining activities in central Florida, this component served to investigate methods to process and utilize the significant by-product streams associated with ethanol production wastewater characteristics and previous experience revealed a consensus toward anaerobic digestion as an economically viable and sustainable by-product recovery scheme, much of this effort focused on examining the aspects of biomass to ethanol conversion and effluent disposition which are expected to impact technical feasibility of anaerobic digestion. To a practical extent, an attempt was made to study the role of feedstock, hydrolysis method, in-plant recycling, microbial toxicity, by-product recovery, feed recovery, nutrient recovery, single-cell protein production treatment and utilization options.

Some specific objective were to:

1. Determine the expected characteristics of stillage wastes from biomass to ethanol production processes and feedstocks significant to the central Florida region.
2. Determine the expected treatability and some of the processing options of the predicted stillage.

3. Determine some of the more suitable post-processing schemes which maximize high-value by-product recovery and/or long term sustainability of the dedicated biomass feedstock supply system.
4. Determine additional information and research needs required to adequately predict the economic and environmental consequences of biomass to ethanol conversion and associated by-product recovery and utilization options.
5. Document the findings of this effort.

Approach

The approach applied to achieve component objectives was to perform a detailed investigation of ethanol production and by-product recovery processes which were expected to result in economic or environmental impacts. To accomplish this effort, a detailed review of the applicable literature was performed. In addition, local, national, and international expertise from academia, industry, and government organizations was sought for input and guidance toward knowledge not immediately available from traditional sources.

An effort was made to synthesize related industrial experience which is believed to be relevant to a dedicated biomass feedstock to ethanol system in the central Florida region. Specific industrial activities considered include: corn and grain ethanol production, sugarcane ethanol production, molasses ethanol production, pulp and paper production, fermentation industry's wastewater treatment and land application, crop production utilizing similar wastewaters, and research and development of economic ligno-cellulosic hydrolysis methods. Efforts also pursued laboratory, pilot-scale, and field and full-scale experience in biomass ethanol production, agronomic studies on ethanol waste utilization, and in anaerobic digestion of stillage from a number of ethanol feedstock.

Conclusions

While the principal aims of some of the objectives were not entirely fulfilled, this effort has resulted in significant progress toward an appreciation of the potential impacts of biomass ethanol production. There is a need for further information. Specific areas of research requiring further study are included. In documenting this effort it is believed this objective is realized. Some specific conclusions from this effort are:

1. Existing research supports the application of anaerobic digestion for biomass to ethanol stillage treatment and biogas recovery.
2. Research also indicates that land application of effluents for nutrient recovery may allow enhanced crop production.
3. Options for enhancing stillage utilization and by-product recovery exist such as feed production through single cell protein and/or algae, and in the recovery of useful organic compounds of industrial significance.

Recommendations

From many of the conclusions of this effort, areas of knowledge which appear to require further investigation are apparent to the authors. While some of the research currently underway both in the U.S. and in other countries at the forefront of commercially viable biomass to ethanol production (eg. Canada, Brazil, New Zealand, etc.), is not immediately available to the authors, it is believed that results of these efforts are not widely available and specific research efforts resulting in information dissemination would help government and industry progress toward economically and environmentally sustainable biomass to ethanol energy production systems. Some of these recommendations include:

1. Hydrolysis stillage characterization data should be obtained for pertinent feedstocks, hydrolysis methods, and fermentation schemes and these results should be considered during feedstock and process selection/optimization.
2. As final selection of feedstock/process is approached, corresponding hydrolysis stillage treatability studies should be performed prior to preliminary process design and cost estimation.
3. As stillage treatability studies are performed, a simultaneous examination of effluent phytotoxicity on pertinent soils and cropping systems should allow methods for ameliorating such effects and to estimate the costs of these methods.
4. Conversion process design and implementation must consider the role of input chemicals and their fate to assure sustainability of the system. Both long-term use of Na (pH control), and the effects of heavy metals (as losses from corrosion of equipment) on the sustainability of the biomass cropping system should be addressed.

Electricity Production: Radioactivity Concerns

Mined phosphate soils contain above average amounts of ^{226}Ra which are taken up by plants grown on these soils. There has been concern that the combustion of this plant material or distribution of the ash from combustion could constitute an environmental hazard. The amount of ^{226}Ra contained in processing waste is determined by soil, plant species and the mix with other fuels. The ^{226}Ra contents common to the project are shown in Table 10-1.

The Florida Institute for Phosphate Research (FIPR) has commissioned extensive research on the radioactivity of mined lands and of food material grown on these lands. the conclusion drawn from these studies is:

"The higher concentrations exhibited by those foods grown on mined phosphate lands result in higher rates of ingestion for radium-226 and higher radiation doses to those individuals ingesting thee foods. The doses however are quite low, even for the hypothetical maximum individual who consumes all study foods from clay lands. The estimated doses, even to the maximum individual, would be a small fraction of natural exposure to environmental radioactivity and would not be considered to be a health hazard." (FIPR Publication No. 05-028-088, October 1990)

Table 10-1. Radium²²⁶ Content of Soil and Biomass Materials

Soil Type	Soil ^a	E-grass ^b	Leu. ^b	Sorghum ^b
	-----pCi g ⁻¹ -----			
Non-phosphatic Soils	.6^c	.03	.04	.05
Unmined Phosphatic Soil	.5	.03	.04	.05
Overburden/Sand Tailings (MOA)	5.2	.06	.09	.16
Phosphatic Clay (CSA)	16.0 (24.3)^b	.09	.13	.24

^a Guidry et. al (1990), Table 7

^b Mislevy, Blue and Roessler (1989)

^c Italicized (non-bold) values are estimated

For a worst case scenario in which elephantgrass and leucaena are grown on clay settling areas the radioactive content of the ash produced by combustion is estimated at 3 pCi g⁻¹ (appendix H). This radioactivity level is about 12% of the radioactivity level of the soil on which the plants are grown.

The Florida Health and Rehabilitative Services (HRS), Office of Radiation Control has considered the issue of the production and disposal of ash from material grown on mined phosphate lands and has determined that ash containing less than 5.0 pCi g⁻¹ of ²²⁶Ra, disposed of by returning to the land, should not create a radiological health hazard. A copy of this HRS opinion is also included in appendix H.

The US Environmental Protection Agency has concluded that, at this time, stack emissions from a specific proposed project in which biofuels mixed with urban wood waste and shredded tires would not be subject to a federal radionuclide emissions standard. It is probable that any new facility, or a change in fuel type for an existing facility, would require an evaluation by the State of Florida of the need for a radiation license. USEPA states that the public health hazard of emissions resulting from the combustion of biomass material containing ²²⁶Ra would be determined by a number of technical considerations (fuel mix and fuel characteristics, conversion process, pollution control equipment, etc.). The hazard status of each proposed project would necessary be determined by the State of Florida as a part of their evaluation of the need for radiation licensing. USEPA comments are included in appendix H.

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Biomass Seed Stock

11. Expanding Seed Stock Plantings

Gordon M. Prine and Donald L. Rockwood¹²

Herbaceous Biomass

Based on superior performance in earlier experiments on phosphatic clay, six vegetatively propagated tall grasses were selected for increase. Grasses included: 2.2 acres of N-51, and 1 acre of PI 300086 elephantgrass (*Pennisetum purpureum*); 2 acres of US72-1153, and 2.3 acres of L79-1002 Energycane; 2.3 acres of US56-9, and .85 acres of US67-2022 sugarcane (*Saccharum* sp.). In addition, 1.7 acres of McCarty Giant and .5 acres of K-8 leucaena (*Leucaena leucocephala*) was planted in May and June, 1994. Growth of the tall grasses was better than normal in response to a wetter than normal summer and fall. Each of the tall grass plantings will permit a ten-fold increase in acreage.

Stands of both leucaena varieties were sparse. The K-8 variety was replanted and the McCarty Giant was inter-planted to improve stands. Only small supplies of leucaena seed are available in Florida and imported seed is very expensive. These plantings will provide for future seed production. Seed of the variety K 636, a cultivar touted for high biomass production, was ordered from Hawaii. The ground was too wet for planting when the seed arrived. It remains in storage for future planting.

Small plots of three hexaploid elephantgrass lines from the breeding program of S.C. Shank, *Pennisetum* breeder for the University of Florida, IFAS, were seeded in phosphatic clay soil at the Mined Lands Agricultural Research/Demonstration Project (MLAR/DP) site in 1994. Only one hexaploid accession had a good stand. The hexaploids can be planted from seed. However, they are not as persistent as the vegetatively propagated elephantgrass because they contain pearl millet germplasm. Observations are being made on how well the seeded elephantgrass accessions grow and persist on phosphatic clay soil. If the seeded elephantgrass are perennial enough, it could greatly reduce the cost of establishing this crop compared to vegetative planting.

Woody Biomass

Progenies and clones in existing genetic tests in central and southern Florida were assessed to identify superior genotypes for commercial use. In August 1994, a clone bank of three *Eucalyptus* species was established on a one acre site on phosphatic clay soil at the MLAR/DP site. Site preparation and maintenance was provided by MLAR/DP equipment and staff. In January 1995, 37 *E. grandis*, 48 *E. camaldulensis*, and one *E. tereticornis* clones in south Florida field trials were felled for propagation by rooted cuttings to establish another clone bank at the MLAR/DP site. Some 80 *E. amplifolia* at three sites were also girdled in March for the same purpose. Seed were collected from superior trees in existing advanced-generation seed orchards of *E. grandis*, *E. camaldulensis*, and *E. tereticornis*.

Three *E. grandis* (10 - 220 ramets each), four *E. camaldulensis* (up to 220 ramets each), and five *E. amplifolia* clones totalling over 1,000 trees were planted on August 19 and 29 to serve

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as sources for production of rooted cuttings. A limited number of *E. amplifolia* clones were added in January 1995. Through January, the trees planted first were up to 6.5 ft tall, with *E. grandis* clones having the greatest vigor. A freeze in February, 1995 did not damage any trees. Soil analyses for the clone bank suggested that phosphatic clay soil has adequate nutrient levels for *Eucalyptus* but may need N amendments for desirable nutrient balance.

A second *Eucalyptus* clone bank at the MLAR/DP site is likely to be planted in July, 1995. Collectively the two clone banks are expected to produce 100,000 cuttings each year.

The best *Eucalyptus* clones can be propagated vegetatively by rooted cuttings, by micropropagation, or by seed. In December 1994, *Eucalyptus* macropropagule, micropropagule, and seedling propagation options were discussed with Twyford International, Inc. in Apopka, Florida. Seed from 16 *E. grandis* and seven *E. camaldulensis* seed orchard trees was collected in September. In November 1994, seed from another 13 *E. grandis* seed orchard trees was collected and processed. The observed seed crop available for *E. grandis* in Spring 1995 is heavy; abundant quantities are expected to be collected in March/April. No seed was obtained for *Sapium sebiferum*, this exotic species is considered to be too invasive for commercial use.

Materials Handling

12. Transportation Costs

Ashley Vincent, Evelyn Vincent, and Alan Hodges¹³

To determine transportation costs for various biomass materials, location of probable production sites were located (see Figure 1-1 in section 1 of this report). Next, the location of existing

Table 12-1. Mined Lands and Energy Facility Location

Facility	Map Name	Adjusted Acreage			Centroid Location	
		Total	CSA	MOA	Lat.	Long.
Mine	Big Four	1,697	1,377	320	27.72	82.01
Mine	Bonny Lake	4,659	3,862	797	27.91	81.83
Mine	Fort Green	6,918	4,648	2,270	27.67	81.92
Mine	Fort Meade	4,140	3,052	1,089	27.69	91.75
Mine	Four Corners	10,459	7,819	2,640	27.64	82.05
Mine	Hardee	364	0	364	27.63	81.83
Mine	Hookers Prairie	2,467	1,538	929	27.73	81.84
Mine	Hopewell	3,537	2,971	567	27.91	82.01
Mine	Kingsford	11,566	10,118	1,448	27.79	81.94
Mine	Lonesome	5,652	5,405	247	27.77	82.01
Mine	New Wales	263	0	263	27.88	81.94
Mine	Nichols	2,837	2,430	407	27.86	81.92
Mine	Noralyn Phosphate	9,461	7,852	1,608	27.84	81.77
Mine	Payne Creek	8,244	5,343	2,901	27.66	81.85
Mine	Peebledale	706	360	347	27.84	81.86
Mine	Rockland	4,855	3,972	888	27.74	81.76
Mine	Saddle Creek	7,035	5,088	1,947	28.08	81.75
Mine	Silver City	2,416	2,003	413	27.78	81.81
Mine	Silver Springs	4,048	8,233	815	27.85	81.70
Mine	Watson	2,203	1,438	765	27.72	81.65
Mine	Hayesworth	na	na	na	27.75	81.94
Mine	CF S. Pasture	na	na	na	27.57	81.85
Mine	Wingate	na	na	na	27.51	82.01

Combust. Plant	ARK Energy				27.85	81.72
Combust. Plant	FPC				27.81	81.79
Combust. Plant	TECO-Seminole				27.64	81.91
Combust. Plant	TECO				27.72	81.91
Combust. Plant	Ridge Generating				28.04	81.77
Ethanol Plant	Mulberry Ethanol (ArKenol)				27.86	81.73
Ethanol Plant	Bartow Ethanol				27.88	81.71

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Table 12-2. Distance from Biomass Production Sites to Plants (straight-line miles)

Map Name	ARK Energy	FPC	TECO Seminole	TECO	Ridge Gen.	ArKenol	Bartow Ethanol	--Nearest Plant-- Combust. Ethanol	
Big Four	19.8	14.9	8.2	6.3	26.4	19.9	21.9	6.3	19.9
Bonny Lake	7.8	7.0	18.6	13.8	9.8	7.3	8.0	7.0	7.3
Fort Green	17.1	12.4	2.1	3.1	26.7	17.5	19.6	2.1	17.5
Fort Meade	10.9	8.7	10.5	10.2	23.8	11.6	13.4	8.7	11.6
Four Corners	24.6	19.7	8.7	10.1	32.2	24.9	26.9	8.7	24.9
Hardee	16.0	12.4	5.3	7.8	28.0	16.6	18.7	5.3	16.6
Hookers Prairie	10.6	6.1	7.5	4.6	21.4	11.1	13.2	4.6	11.1
Hopewell	17.8	14.80	19.4	14.7	16.8	17.4	18.5	14.7	17.4
Kingsford	13.5	8.8	10.4	5.5	19.6	13.5	15.4	5.5	13.5
Lonesome	18.0	13.2	10.7	7.0	23.1	17.9	19.8	7.0	17.9
New Wales	13.6	9.3	12.7	7.8	18.1	13.4	15.1	7.8	13.4
Nichols	12.0	8.4	14.8	9.8	15.4	11.7	13.2	8.4	11.7
Noralyn	2.8	2.7	16.3	12.4	13.2	2.7	4.7	2.7	2.7
Payne Creek	14.7	10.6	4.0	5.1	26.0	15.2	17.3	4.0	15.2
Pebbledale	8.3	4.4	13.6	8.9	14.8	8.1	9.9	4.4	8.1
Rockland	7.7	5.1	11.3	9.2	20.3	8.3	10.3	5.1	8.3
Saddle Creek	16.1	18.7	31.5	26.8	3.2	15.3	13.9	3.2	15.3
Sivler City	6.7	2.1	11.5	7.9	17.6	7.1	9.2	2.1	7.1
Silver Springs	1.8	6.7	19.6	16.3	13.3	2.0	2.0	1.8	2.0
Watson	9.5	10.4	16.7	15.8	22.6	10.3	11.3	9.5	10.3
Haynesworth	14.5	9.6	7.6	2.9	22.0	14.7	16.7	2.9	14.7
CF S. Pasture	20.6	16.9	6.1	10.6	32.4	21.2	23.3	6.1	21.2
Wingate	<u>28.6</u>	<u>24.1</u>	<u>10.5</u>	<u>14.9</u>	<u>38.6</u>	<u>29.0</u>	<u>31.1</u>	<u>10.5</u>	<u>29.0</u>
Average	13.6	10.7	12.1	10.1	21.1	13.8	15.4	6.0	13.8

conversion facilities were identified. The locational relationships of production sites and conversion facilities are noted in table 12-1. Straight line milage from each production site to each conversion facility was calculated along with the average distance of each production site from each conversion facility (table 12-2). Hauling distance in relation to the time required for loading and unloading was such that hourly rates rather than milage was used to estimate hauling costs. Transportation costs for the various biomass crops is shown in table 12-3.

For sugarcane, two harvesting and pre-processing systems were assumed. One system harvests sugarcane as billets. The billets are transported to a central processing facility, ground and pressed. Ideally, the pre-processing facility would be located near the largest concentration of production sites or co-located with both a conventional ethanol plant and a cellulosic conversion plant to eliminate further transportation costs. Should the juice have to be transported, concentrating to 24 degrees Brix would reduce transportation costs. Long term storage would require further concentration to 70 degrees Brix.

Table 12-3. Transportation Costs for Biomass Materials in Central Florida

Biomass Materials	----Capacity per Load----			Cost per Hour (dollars)	Trip Cycle (hours)	Cost per Dry Ton (dollars)	Destination
	Green (tons)	Dry (tons)	Liquid (gal.)				
Woody Biomass ^a	25.0	21.25		\$50.00	1.20	\$2.82	Direct Combustion Lignocellulose Conversion
Sugarcane ^b							Pre-processing & Lignocellulose Conversion
Billets (75% moist.)	25.0	6.14		50.0	1.37	11.16	
Presscake (61%)	25.0	9.75		50.0	1.37	7.03	Lignocellulose Conv.
Juice @ 12.5 Deg Brix	25.0	3.25	5,750	50.0	1.50	23.08	Ethanol Facility
@ 24.0 Deg Brix	25.0	6.21	5,500	50.0	1.50	12.08	Ethanol Facility
@ 70.0 Deg Brix	25.0	17.72	4,500	50.0	1.50	4.23	Ethanol Facility
Elephantgrass							Direct Combustion Pre-processing & Lignocellulose Conv.
Round Bales ^c @ 1,500 lb	12.0	9.60		50.0	1.37	7.14	
Chopped (75% moisture)	25.0	6.25		50.0	1.37	10.96	Lignocellulose Conv.
Leucaena							
Chipped (15% moisture)	25.0	21.25		50.0	1.37	3.22	Direct Combustion Lignocellulose Conv.

^a Field dried chips, 15% moisture.

^b Sugarcane harvested as billets to be transported to a central processing facility.

^c Field dried to 20% moisture.

With an alternative system, sugarcane would be harvested with a forage harvester and transported to presses located on the perimeter of the field. A portion of the juice would be transported at 12.5 degrees Brix direct to a conventional ethanol facility while some would be transported for concentration and storage. Fresh presscake could be transported to a lignocellulose conversion facility or ensiled on the edge of the field for later use.

With all biomass materials, moisture content is a major factor in transportation costs. Reducing moisture content in the field greatly reduces transportation costs.

13. Sugarcane Pressing Strategies

Ashley Vincent and Evelyn Vincent¹⁴

Introduction

Approximately 1,000 lbs of US67-2022 sugarcane was cut from demonstration plots at the Mined Lands Agricultural Research/Demonstration Project (MLAR/DP) site near Bartow, Fla. on 12/5/94. The material was held overnight as whole stalks. On the morning of 12/6 the material was chopped with a W W Grinder chipper and transported to Vincent Corp. in Tampa for pressing. Because of a press malfunction the material was held overnight in cold storage and pressed with a 6 inch Vincent VP-6 laboratory screw press on the morning of 12/7. Single, and simulated double, and triple pressing was made on this material. Percent moisture was measured with an Ohaus moisture tester. Samples of presscake from each pressing were saved as both fresh material (refrigerated) and as silage (stored in 5 gal. buckets) for BioEnergy Intl. Additional samples of presscake from each of the three pressings were air dried for analysis for direct combustion by Ridge Generating Station. Juice samples from each pressing were saved for fermentation to ethanol by Bartow Ethanol, Inc.

Single Pressing

Presscake and liquid from about 1,000 lbs of sugarcane were weighed and divided into three parts. Percent moisture in the presscake was recorded in degrees Brix using a hand-held refractometer and percent moisture in the presscake was recorded. Forty percent of the presscake and press liquid was set aside to be used for single pressing samples. The remaining 60 percent of each was divided into equal parts for simulated double pressing and triple pressing tests. Results of the single pressing operation are shown in table 13-1.

Table 13-1. Results of Single Pressing of Chopped Sugarcane

Product	Lbs.	Press Ratio ^a	Deg. Brix	Water %	Solids %
Chopped Sugarcane	366			76.3	23.7
Presscake	180		12.7	66.0	34.0
Press Liquid (Juice)	186	50.8	12.7	87.3	12.7

^a Press liquid/chopped sugarcane pressed

Double Pressing

In the double pressing operation, the presscake from single pressing was mixed with fresh water (75% by weight). Approximately five minutes were allowed for the mixture to reach equilibrium. Total weight and percent moisture were recorded for this material as inbound to the second stage pressing operation. After pressing, weight and percent moisture of the presscake were recorded, and the presscake set aside for later analysis. Press liquid from the second stage pressing was weighed and degree Brix recorded. The second stage press liquid was then mixed with the first stage press liquid designated for double pressing. Degrees Brix of this composite liquid was recorded and the

liquid set aside to be used for sample of press liquid from double pressing to be fermented by Bartow Ethanol. Results of the double pressing operation is shown in table 13-2.

Table 13-2. Results of Double Pressing of Chopped Sugarcane

Product	Lbs.	Press Ratio ^a	Deg. Brix	Water %	Solids %
First Stage					
Chopped Sugarcane	274			76.3	23.7
Presscake	134		12.7	66.0	34.0
Press Liquid (juice)	140	51.1	12.7	87.3	12.7
Second Stage					
Water Added	100				
Material Inbound ^b	234		6.4	80.5	19.5
Presscake	128		6.4	68.8	31.2
Press Liquid	106	45.3	6.4	93.6	6.4
Combined Liquid	246		10.0	90.0	10.0

^a Press liquid/chopped sugarcane pressed.

^b Includes presscake from first stage plus 100 lb water.

Triple Pressing

Presscake that had been designated for triple pressing, from the first stage operation, was mixed with 10 degrees Brix juice (80% by weight) to simulate recirculation of juice from the third stage pressing. (Juice with a 7 degrees Brix reading would be more effective, however, a higher Brix level was used in this case.) Approximately five minutes were allowed for the mixture to reach equilibrium. Total weight and percent moisture were recorded for this material as inbound to the second stage pressing operation. After pressing, (second stage) weight and percent moisture of the presscake were recorded as was degrees Brix for the press liquid. This presscake was then mixed with fresh water (75% by weight) and allowed to reach equilibrium. Total weight and percent moisture were recorded for this material as inbound to the third stage pressing operation. After pressing, weight and percent moisture of the presscake were recorded and the presscake set aside as sample material from triple pressing. Press liquid from this third stage pressing was weighed and degrees Brix recorded. Liquid from the first and second stages of the triple pressing simulation were mixed. Total weight and degrees Brix of this composite were recorded and the liquid set aside for samples from triple pressing to go to Bartow Ethanol for fermentation. Data from the simulated triple pressing operation are shown in table 13-3.

Table 13-3. Results of Triple Pressing of Chopped Sugarcane

Product	Lbs.	Press Ratio ^a	Deg. Brix	Water %	Solids %
First Stage					
Chopped Sugarcane	274			76.3	23.7
Presscake	134			66.0	34.0
Press Liquid (juice)	140	51.1	12.7	87.3	12.7
Second Stage					
Press Liquid Added	106		10.0	90.0	10.0
Material Inbound ^b	240		11.3	76.6	23.4
Presscake	128		11.3	64.5	35.5
Press Liquid	112	46.7	11.3	88.7	11.3
Third Stage					
Water Added	96			100.0	0.0
Material Inbound ^c	224		5.6	79.7	20.3
Presscake	130		5.6	69.5	30.5
Press Liquid	94	42.0	5.6	94.4	5.6
Combined Liquid	346		10.3	89.7	10.3

^a Press liquid/chopped sugarcane pressed.

^b Includes presscake from first stage plus 106 lb press liquid from third stage.

^c Includes presscake from second stage plus 96 lbs of water.

In addition to their use as feedstocks for lignocellulose conversion to ethanol, sugarcane, presscake, elephantgrass, leucaena, and *Eucalyptus* may prove to be superior feedstocks for valuable products such as high purity cellulose and other chemicals. NREL's Clean fractionation process of separation of materials into constituents of cellulose, hemicellulose, and lignin shows great promise in offering an efficient and economical method opening the way of all three biomass fractions as sources of valuable chemicals and materials. This process could potentially offer glucose and xylose at lower cost for conversion to ethanol or for other marketable products, as well as making the lignin available for profitable uses. Patent applications for this process have been filed and further information is scheduled to be presented in the next few months. Biomass crops such as those grown on reclaimed phosphate are being considered as feedstocks for this process.

Sugarcane Presscake as Cattle Feed

Samples of both ensiled and fresh sugarcane presscake along with whole chopped sugarcane were sent to the Northeast DHIA Forage Testing Laboratory for analysis as cattle feed. Results are shown in table 13-4.

Results of the feed analysis were sent to Dr. Charles Staples, a forage crop specialist in the Dairy Science Dept. at the University of Florida. It was Dr. Staples opinion that the quality of the sugarcane forages were very low. The sugarcane forage fed alone would not support the maintenance needs of a ruminant.

Table 13-4. Feed Analysis of Sugarcane, Sugarcane Presscake, and Presscake Silage - Northeast DHIA Testing Laboratory, Ithaca, NY

Harv. Date, Variety, & Material	CP ^a	ADF	NDF	NSC	TDN	Ca	P	Mg	K	Na	Fe	Zn	Cu	Mn	Mo
	-----%										-----PPM-----				
1/4/95 US67-2022 Sugarcane Presscake Fresh	2.4	43.5	68.5	22.1	58.0	.16	.10	.07	.84	.003	145	11	5	12	<1
12/8/94 CP72-1210 Sugarcane Presscake Silage	2.6	53.6	78.5	12.7	50.0	.29	.15	.11	.90	.005	194	21	7	60	<1
12/9/94 CP72-1210 Sugarcane Whole Plant Fresh	2.8	45.5	66.8	23.4	56.0	.24	.23	.13	1.42	.004	302	20	3	67	<1
12/9/94 CP72-1210 Sugarcane Presscake Fresh	2.6	49.8	74.5	15.9	53.0	.34	.15	.11	.89	.006	286	21	6	61	1.1

^aCP=Crude Protein, ADF=Acid Detergent Fiber, NDF=Neutral Detergent Fiber, NSC=Nonstructural Carbohydrates, TDN=Total Digestible Nutrients, CA=Calcium, P=Phosphorus, Mg=Magnesium, K=Potassium, Na=Sodium, Fe=Iron, Zn=zinc, Cu=copper, Mn=Manganese, Mo=Molybdenum.

14. Storage Costs

Ashley Vincent and Evelyn Vincent¹⁵

Woody Biomass

Three harvest methods are envisioned for woody biomass materials: feller-buncher/chipper, billet/chipper, and forage chopper. With feller-buncher harvesting, materials will be left in the field or field margin for a period of time to dry. Once dry enough, the materials may be chipped and loaded onto trucks in one operation and transported to the conversion facility. Woody biomass harvested with a forage chopper will not be suitable for direct combustion because of high moisture content. Also, because of moisture levels, long term storage will not be practical because of possible decay in large piles, unless the piles are turned frequently. Harvest season for many woody biomass species can be extended year-around, thus reducing the need for storage.

Sugarcane Juice

Raw sugarcane juice will rapidly ferment and cannot be stored. To prepare sugarcane juice for long term storage it must be concentrated to molasses. To operate a 5,000,000 gal per year capacity conventional ethanol plant on sugarcane juice will require storing 6,700,000 gal of juice concentrated to 70 degrees Brix. Storage costs as reported in table 14-1 reflect the cost of storage tanks and pumps amortized over 10 years.

Table 14-1. Storage Costs for Biomass Materials

Biomass Materials	Type of Storage	Capacity per Year	Cost Dollars/dry ton	Cost \$/ton per day
Woody Biomass and Leucaena	Field-dried 2-6 weeks moved to roadside piles for storage: chipper loads for transport		Covered in harvest costs	
Sugarcane (88,000 dry tons/yr) Juice at 70 Deg Brix	Concentrated for storage. Four tanks 87ft dia x 40 ft high	6,700,000 gal.	2.55	0.01
Presscake (ensiled)	Piles on ground	190,000 yd ³ 10ft pile covers 12 acres	7.29	0.03
Elephantgrass (128,000 dry tons/yr) in Round Bales @ 1,500 lbs	Roadside storage	1,000,000 yd ³ 10 ft pile covers 63 acres	Covered in harvest cost	

Dr. Ashley Vincent and Mrs. Evelyn Vincent, Savant-Vincent, Inc., 166 Baltic Circle, Tampa, FL 33606.

Ensiled Presscake

Using the same scenario of supplying a 5,000,000 gal per year ethanol plant with sugarcane, 49,000 dry tons of presscake (190,000 yd³) will be stored at the field site as silage. Costs shown in table 14-1 reflect cost of trucks and loaders needed to transfer the presscake and pack it to exclude air. No land charge is made because charge is included in land rent.

Elephantgrass Stored in Large Round Bales

Field dried and baled elephantgrass can be moved to the side of the field for temporary storage. A total of 128,000 dry tons of elephantgrass would represent a volume of about 1,000,000 yd³. Since this material will be moved to the field margin or road side in the harvest operation, no additional cost for storage is required.

Conversion Methods

15 Fermentation of Sugarcane Juice to Ethanol

Nathan Duncan¹⁶

Introduction

A total of eleven (11) 1 quart samples of sugarcane juice were received on 12/12/94. Four additional samples were received on 1/6/95. The samples came from press tests conducted by Savant-Vincent, Inc. on a 6 inch Vincent laboratory press with materials supplied by the Mined Lands Agricultural Research/Demonstration Project. Samples had been refrigerated when

Table 13-1. Fermentation of Sugarcane Juice to Ethanol

Sample	Beginning Brix	Final Brix	Beginning pH	Final pH	Fermentation Time - Hrs.	% Ethanol by Vol.
US78-1009 ^a						
Rep. #1	14.5	4.2	4.35	3.93	53.0	5.0
Rep. #2	13.5	4.6	4.95	4.17	53.0	5.1
Rep. #3	11.0	2.3	5.51	4.23	53.0	3.9
Rep. #4	14.4	2.8	4.78	3.99	72.0	5.5
Average	13.4	3.5	4.90	4.08	57.8	4.9
CP72-1210						
Rep. #1	14.5	3.9	4.31	3.89	53.0	5.1
Rep. #2	13.7	4.7	4.21	3.90	53.0	5.0
Rep. #3	15.0	3.1	5.43	4.00	48.0	6.2
Rep. #4	14.9	2.5	5.44	4.08	48.0	6.3
Average	14.5	3.6	4.85	3.97	50.5	5.6
US 67-2022						
Rep. #1	14.9	2.3	5.03	3.95	71	7.8
Rep. #2	14.8	3.7	5.09	4.00	71	7.8
Rep. #3	15.5	3.4	5.15	4.21	72	7.8
Rep. #4	13.9	1.2	5.09	4.15	72	7.0
Average	14.8	2.6	5.09	4.08	72	7.6
US 67-2022						
Single Pass	13.3	2.7	4.24	3.72	48	5.7
Double Pass	9.5	2.5	4.25	3.61	48	3.8
Triple Pass	10.1	2.7	3.96	3.65	48	4.0

^a Sugarcane or energycane variety

Mr. Nathan Duncan, Production Manager, Bartow Ethanol, Inc., P.O. Box 1966, Bartow, FL 33831.

received and were maintained under refrigeration until processed. Results of the fermentations are shown in table 13-1. One sample each for single, double and triple pressing simulations of sugarcane variety US 67-2022 was received along with four samples each of pressings from US78-1009 and US72-1210. As a backup to December samplings of US67-2022 an additional four samples were taken on January 4th, ground and pressed on January 5th and delivered to Bartow Ethanol on January 6th.

Fermentation Procedure

Standard sample beakers were used. Each sample of juice was tested to determine amount of sugars present in degrees Brix. Next, pH was determined with a calibrated pH meter. The pH is a measure of hydrogen ion concentration. Yeast is used to ferment the juice and yeast cells grow best if the pH range is from 4.0 to 5.5. Two methods were used to determine degrees Brix, a hand refractometer and a hydrometer. The hand refractometer is a hand-held device. A few drops of juice are placed on a glass in the end of the device. The device is held up to a light source while the operator looks through an eye piece and reads the results from a built-in graph. The hand held refractometer is not as accurate as a hydrometer. The hydrometer is placed directly in the juice sample and read. The hydrometer used here had a built-in temperature correction scale.

After determining the amount of sugars and pH, a 500 mL beaker was filled to the 500 mL mark with juice. Next, 5 g of Fermipan instant yeast was added. After mixing the yeast and juice, all data was entered on a fermentation sheet. Information on the sheet included: date started, date finished, sample I.D. #, hydrometer Brix reading, refractometer Brix reading, pH, fermentation time in hrs, and ethanol by volume.

After 24 hrs tests were repeated. After 48 hrs the liquid was tested for ethanol. The ethanol test was done with an ebulliometer. The ebulliometer is a device that measures the percent of ethanol by boiling the sample at ambient barometric pressure. Then by using a chart corrections are made for standard pressure.

Fermentation is complete when the Brix reading stops falling. A complete fermentation will result in 0% Brix or sugars remaining. This is not always possible, however. Based on observations on this project one should be able to utilize 95 to 98.5% of the sugars and starches.

Conclusions

All the samples seemed to have had a rapid fermentation period (less than 72 hrs.). However, most left 1.5° - 3.0° Brix, which I believe can be utilized by processing through the cooking process. By adding enzymes and heating the product to certain temperatures before fermenting, you can expect complete conversions of the available sugars and starches. this should yield on average an extra 1% to 2% of alcohol.

16 Conversion of Cellulosic Biomass to Ethanol

Abdolkarim Asghari and John Gerber¹⁷

Summary

Leucaena, elephantgrass, and different preparations of sugarcane were analyzed for their total composition including hot water extractables, cellulose, hemicellulose, and lignin (including ash) contents. Total sugar assay (TSA) procedure, developed at BioEnergy, was used in this process. The composition and concentration of sugars in cellulose and hemicellulose fractions were determined with high performance liquid chromatography. Hemicellulose fractions of these agricultural products were extracted by treating the materials with dilute sulfuric acid under steam pressure. The hemicellulose hydrolysates were fermented to ethanol by recombinant *Escherichia coli* KO11. Lime was used for mitigating the inhibitors present in the syrup prior to fermentation. Data regarding sugar yields in the hydrolysis and fermentation time, yield, and efficiency, using laboratory and commercial grade nutrients, are reported for each feedstock.

Introduction

During the past few years ethanol has established itself as a reliable additive for production of oxygenated fuels for transportation. In addition to corn and other sugar rich food crops, ethanol can be made from hemicellulose and cellulose parts; wood chips, corn stover, sugarcane bagasse, grass, and other agricultural materials. Also known as lignocellulosic materials, agricultural materials are under utilized, and in many cases they are considered wastes which must be disposed of properly. Conversion of these materials to ethanol can add value to the product and may remediate a waste disposal problem. Hemicellulose, and/or cellulose components of these materials must be converted into monomer sugars before they can be converted to ethanol by microorganisms.

Mild acid treatment of biomass is considered to be the most feasible method for hydrolysis of hemicellulose. Much harsher conditions are required to get cellulose converted to glucose. Studies are under way to examine the feasibility of using cellulases for hydrolysis of cellulose. Currently, high price of enzymes makes this process less attractive. Yeast, and other microorganisms used in sugar based ethanol industry, can easily convert glucose to ethanol, but they fail to efficiently convert all sugars present in hemicellulose hydrolysate to ethanol. BioEnergy holds the exclusive right to the patented *E. coli* and several other recombinant bacteria which are capable of efficiently converting all sugars present in biomass into ethanol. This includes both cellulose and hemicellulose portions of biomass. The conditions for acid hydrolysis and microbial fermentation of sugarcane, elephantgrass, and leucaena are reported in this study.

In addition, samples of sugarcane presscake silage, dried sugarcane presscake, dried elephantgrass, and dried leucaena were sent to the NREL Field Test Laboratory in Golden, Colorado. Results of that analysis is presented in appendix I.

Dr. Abdolkarim Asghari, Microbiology and Cell Science Dept., Univ. of Fla., P.O. Box 110700, Gainesville, FL 32611-0700. Dr. John Gerber, 1126 NW 57th St. Gainesville, FL 32605. (Both formerly with BioEnergy, Intl.)

Materials and Methods

Hemicellulose Hydrolysis; Hydrolysis was carried out in a continuously rotating reactor with direct steam injection. Materials were cooked in dilute sulfuric acid (range 1 to 4% w/w) at 120 to 140°C with variable solid to liquid ratio (10 to 30%) for different length of time. Some of the conditions are considered proprietary, but the exact conditions may vary from one feed stock to the other. Hemicellulose hydrolysate containing dissolved sugars was recovered using a basket centrifuge. The syrup can be kept either at room temperature or stored at 4°C.

Toxic Amelioration; Acid hydrolysis of biomass produces chemicals that are inhibitory to microorganisms. Failure to remove or properly inactivate these mostly phenolic compounds will result in unsuccessful or inefficient fermentation. Lime is used to mitigate the inhibitors. At BioEnergy we have developed processes for mitigation of inhibitors with minimal sugar loss for different feedstocks. The exact time, temperature, and pH for liming varies with different type of biomass.

Fermentation Conditions; Fermentation were conducted at pH 6.0-6.5 and 35°C in volume ranging from 20ml to 350 ml. Inoculum was prepared in Luria Broth supplemented with xylose and diluted 10 fold into the fermentation media (containing hydrolysate and nutrients). Nutrient source was either combination of Difco yeast extract and tryptone or corn steep liquor supplemented with crude yeast autolysate.

Nutrients and Inoculum Preparation; At BioEnergy we have done an extensive study in developing the optimum conditions for seed preparation. We have a system to produce seeds for different volume using different substrate as sugar source. We have examined a variety of commercial grade nutrients. One of the combinations (corn steep liquor and yeast autolysate) were used in this study. We have been able to dramatically reduce the cost of nutrients.

Analysis; Ground materials were treated with different concentrations of acid, weighted and analyzed for sugar composition after each treatment. Sugars concentration and compositions were determined with an HPLC instrument, and ethanol present in fermentation medium was measured by a gas chromatograph. All experiments were done in triplicates.

Results and Discussion

Composition of leucaena, elephantgrass, and sugarcane; the amount of hemicellulose and other components present in each sample were determined with Total Sugar Assay (TSA). In this assay ground materials were treated with different concentrations of sulfuric acids, dried, and weighted after each treatment. Liquid phases were recovered by filtration and analyzed for concentration and type of sugars present. Figures 16-1 to 16-7 depict the results of these studies. Materials, dissolved in hot water during the first wash, were collectively called hot water extractables (HWE). HWE of sugar cane samples were tested for the presence of sugars. Both samples of sugar cane, fresh and silage contained about 6 g/L (fructose and glucose). These two samples also contained the highest percent of HWE among all the samples tested. Unknown portion was the amount unaccounted for after each treatment. This could include destroyed (or modified) sugars, sugar not recognized by HPLC, organic acids, or other chemicals.

Leucaena had the lowest amount of hemicellulose (13.1%). Sugarcane and elephantgrass were found to have about 20% hemicellulose. There were no significant difference between

hemicellulose components of fresh and air dried elephant grass. However, pressed sugarcane samples had (as much as 5%) more hemicellulose than whole sugarcane samples. Others (including BioEnergy) have shown that sugarcane bagasse contains 20-25% hemicellulose. Sugar contents of sugarcane may vary depending on growth conditions or time of harvest. The above data indicates that pressed sugarcane and elephantgrass have more hemicellulose than leucaena.

Numerous studies have reported the acid concentrations, pHs, temperatures, pressures, times, etc. needed to hydrolyze hemicellulose for lignocellulosic materials. In this study two Kg (dry wt) of the material was cooked in dilute sulfuric acid under pressure for 30 minutes. Hydrolysate with close to maximum sugar yield was produced (Table 1). Sugar concentration seemed to be low. It is possible to increase concentration by using a higher solid to liquid ratio, but the yield will drop as the amount of solid in the reactor increases. Sugars can be concentrated by ultra filtration, evaporation, or reverse osmosis. Xylose, glucose, and arabinose were the most abundant sugars in hemicellulose hydrolysate from all materials tested (Table 16-2).

Inhibitor Mitigation

The techniques used cannot be explained in great detail. This is an area which BioEnergy has proprietary information. BioEnergy has a process which effectively mitigates the inhibitors present in the hydrolysate. Figure 16-8 shows results of such experiments. Hydrated lime is used in the process to raise the pH. The process successfully mitigated all samples tested in this study. This is a simple, cheap, and more cost effective process than others.

Fermentation

Hemicellulose hydrolysates from all samples were efficiently fermented to ethanol. Corn steep liquor and crude yeast autolysate were equal to laboratory grade nutrients. Fermentations were complete within 24 hr, since the bacteria ran out of sugar. Previous studies have shown that the recombinant *E. coli* can tolerate much higher ethanol level than what is allowed by most hydrolysates. Ethanol concentration of over 6% (w/w) was achieved in several occasions. This was done without addition of any extra nutrients (data not reported here). Yields from these fermentations approached or exceeded the theoretical maximum, 0.51 g ethanol/g sugar. Table 16-1 depicts the results of fermentation study. Fermentation volume in this study ranged from 20 ml to 350 ml. At BioEnergy we have performed fermentations with volume ranged 20 ml to 200 l. Figure 16-9 shows the fermentation of sugarcane bagasse hydrolysate with KO11 at the 5 gal level.

Between 25 and 35 percent of the biomass samples tested in this study were cellulose. Table 16-3 shows the amount of ethanol which can be produced per dry ton of each sample when hemicellulose and/or cellulose contents are completely hydrolyzed. Very harsh chemical treatment is necessary to break down cellulose polymers into glucose monomers. Mild pre-treated cellulose (under conditions very similar to hemicellulose hydrolysis) can easily be broken down by cellulase enzymes. Table 16-3 shows that between 2.5 and 3.5 times more ethanol is produced when both cellulose and hemicellulose portions of biomass are completely hydrolyzed. This will greatly reduce the cost of raw materials. The major hurdle in this process is the complete hydrolysis of cellulose. Chemical treatment is not practical, and enzyme treatment is very expensive.

Table 16-1. Ethanol Production from Hemicellulose Hydrolysate by E.Coli KO11

Substrate ^a	Nutrient	Sugar (g/L)	EtOH (g/L)	Yield (gEtOH/g Substrate)	Efficiency of Conversion
Leucaena	LB ^b	32	17	0.53	104
	CSL+YA ^c	32	16	0.50	98
Elephantgrass (Fresh)	LB	66	30	0.45	89
	CSL+YA	66	31	0.47	92
Elephantgrass (Silage)	LB	49	23	0.47	92
	CSL+YA	49	25	0.51	100
Sugarcane (Fresh)	LB	38	20	0.52	103
	CSL+YA	38	20	0.52	103
Sugarcane (Silage)	LB	34	17	0.50	98
	CSL+YA	34	18	0.53	104
Sugarcane (Presscake)	LB	33	14	0.42	83
	CSL+YA	33	15	0.46	90

^a Hydrolysate from *Eucalyptus* was not fermented

^b Luria Broth

^c Corn Steep Liquor+Yeast Autolysate

Table 16-2. Sugar Composition of Hemicellulose Hydrolysate from Agricultural Products

-----Sugar Composition (% of total)-----						
Agricultural Crop	Glucose	Xylose	Galactose	Arabinose	Hydrolysate Total Sugar(g/L)	Sugar Yield g/g Substrate
Leucaena	28	51	10	11	32	0.13
Elephantgrass	17	68	6	9	54	0.21
Sugarcane	18	63	5	14	38	0.20
Sugarcane Presscake	6	79	6	9	33	0.17
<i>Eucalyptus</i>	5	60	23	7	54	0.12

Table 16-3. Production of Ethanol from Agricultural Products Using KO11

Biomass Crop	Composition		Lb Sugar/Ton of Biomass		Ethanol Yield (gal)		Total Ethanol/Dry Ton of Biomass
	Hemi ^a	Cell ^b	Hemi	Cell	Hemi	Cell	
Leucaena	13%	34%	260	680	18	47	65
Elephantgrass	21%	31%	420	620	29	43	72
Sugarcane	20%	34%	400	680	28	47	75
<i>Eucalyptus</i>	24%	n.d. ^c	480	n.d.	36	n.d.	n.d.
Sugarcane ^d	25-35%	34%	500-700	680	35-49	47	82-96 <i>289</i>

^a Percent hemicellulose in biomass material

^b Percent cellulose in biomass material

^c n.d. = not determined

^d Analysis reported by others

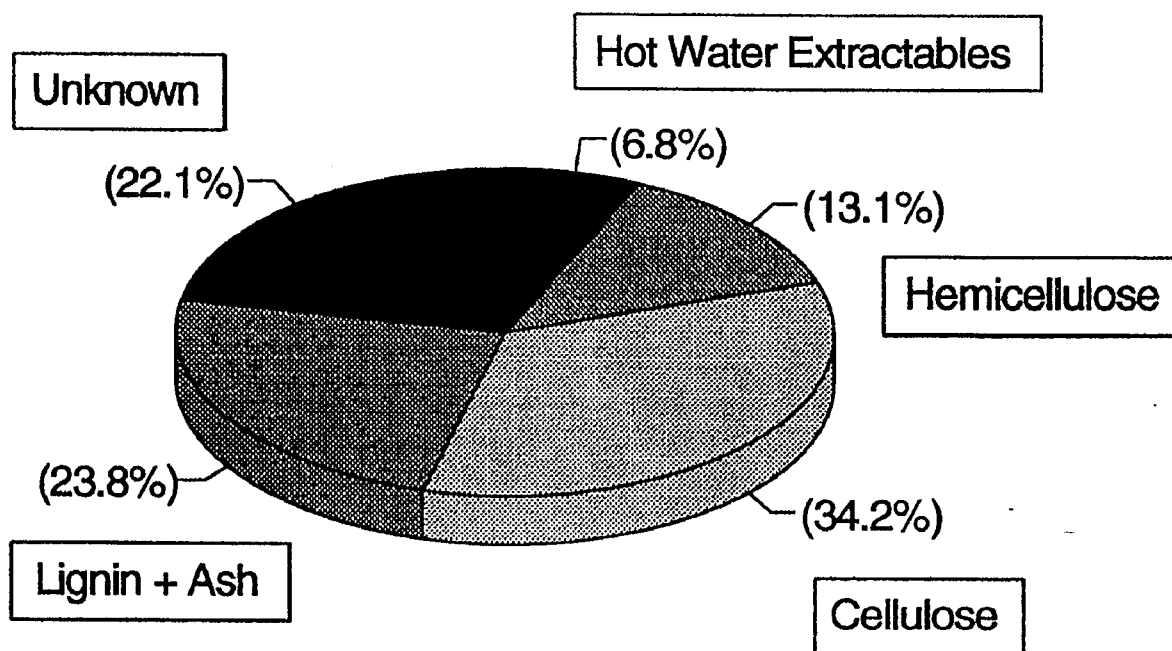


Figure 16-1 Total compositions of whole leucaena determined by total sugar analysis procedure (TSA).

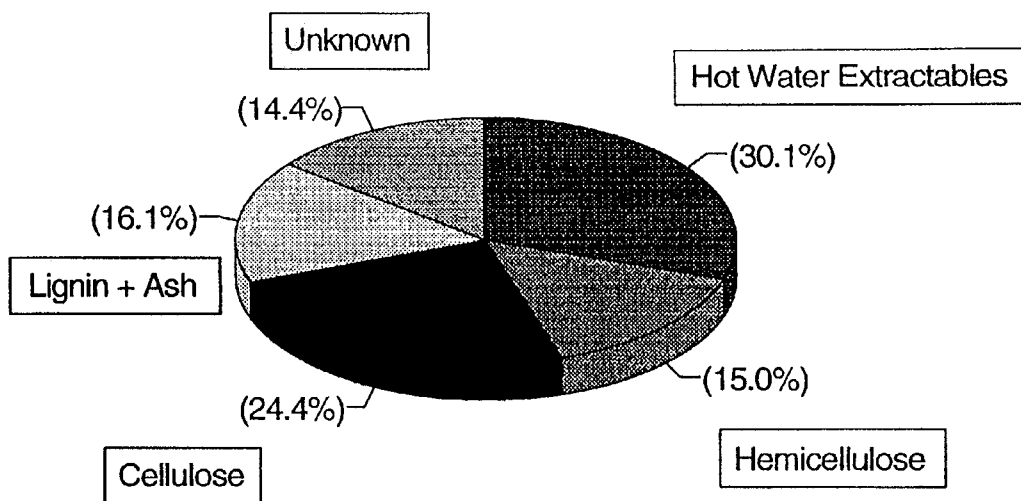


Figure 16-2. Total composition of sugarcane silage determined by total sugar analysis procedure (TSA).

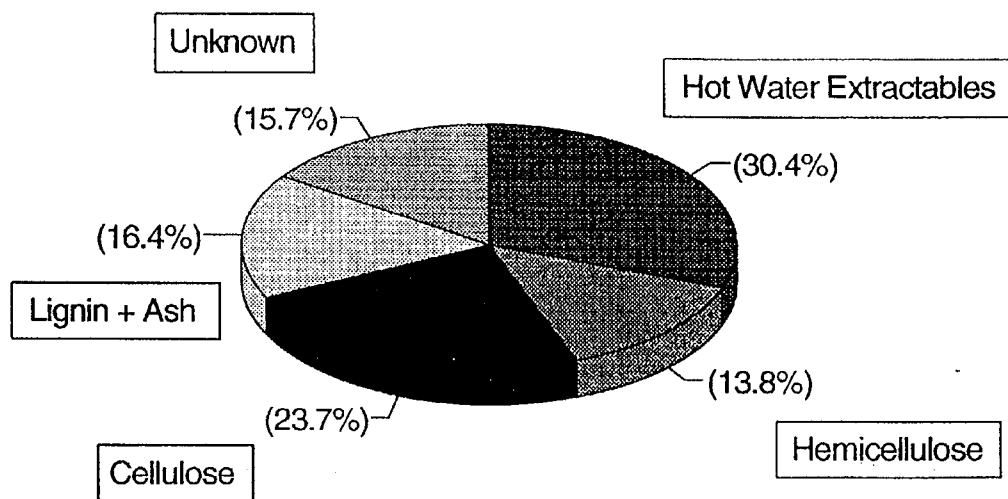


Figure 16-3. Total composition of fresh sugarcane determined by total sugar analysis procedure (TSA).

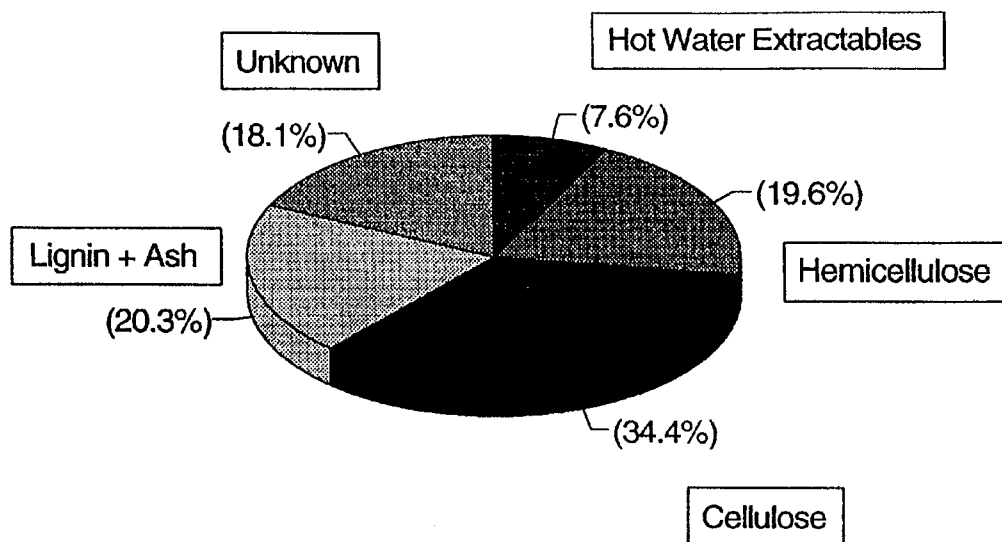


Figure 16-4. Total composition of sugarcane presscake (3 press) silage determined by total sugar analysis procedure (TSA).

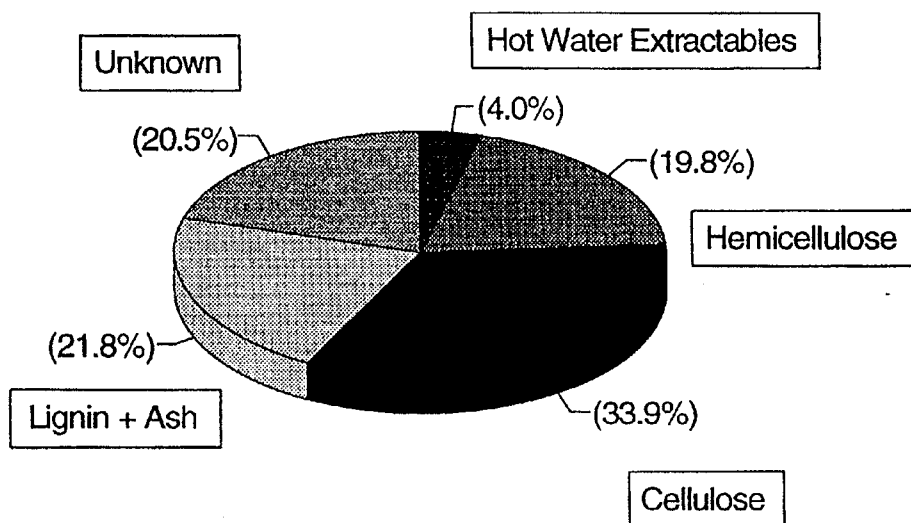


Figure 16-5. Total composition of sugarcane presscake (3-press) fresh determined by total sugar analysis procedure (TSA).

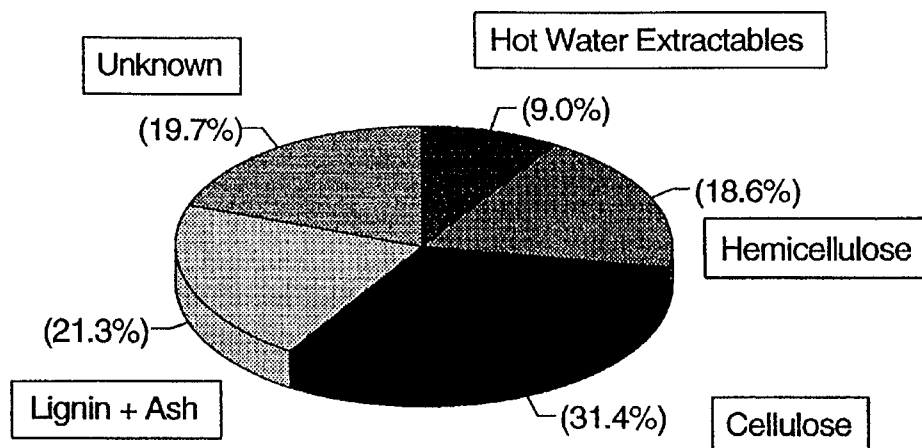


Figure 16-6. Total composition of fresh elephantgrass determined by total sugar analysis procedure (TSA).

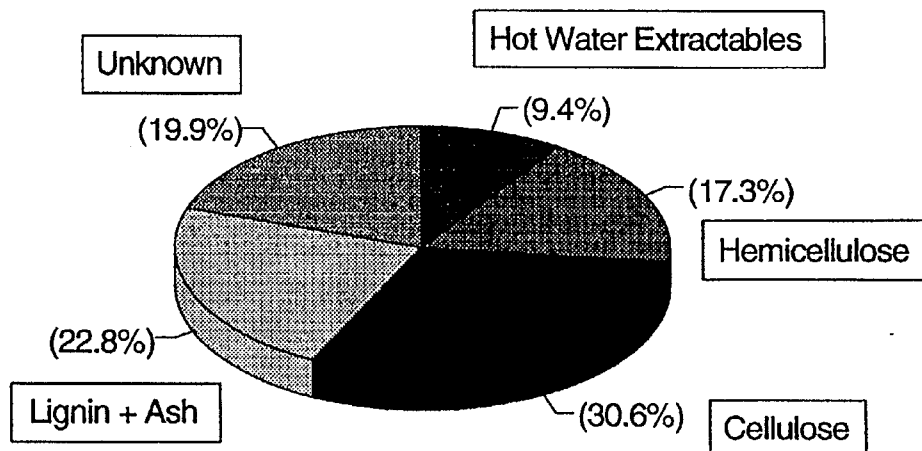


Figure 16-7. Total compositions of air dried elephantgrass determined by total sugar analysis procedure (TSA).

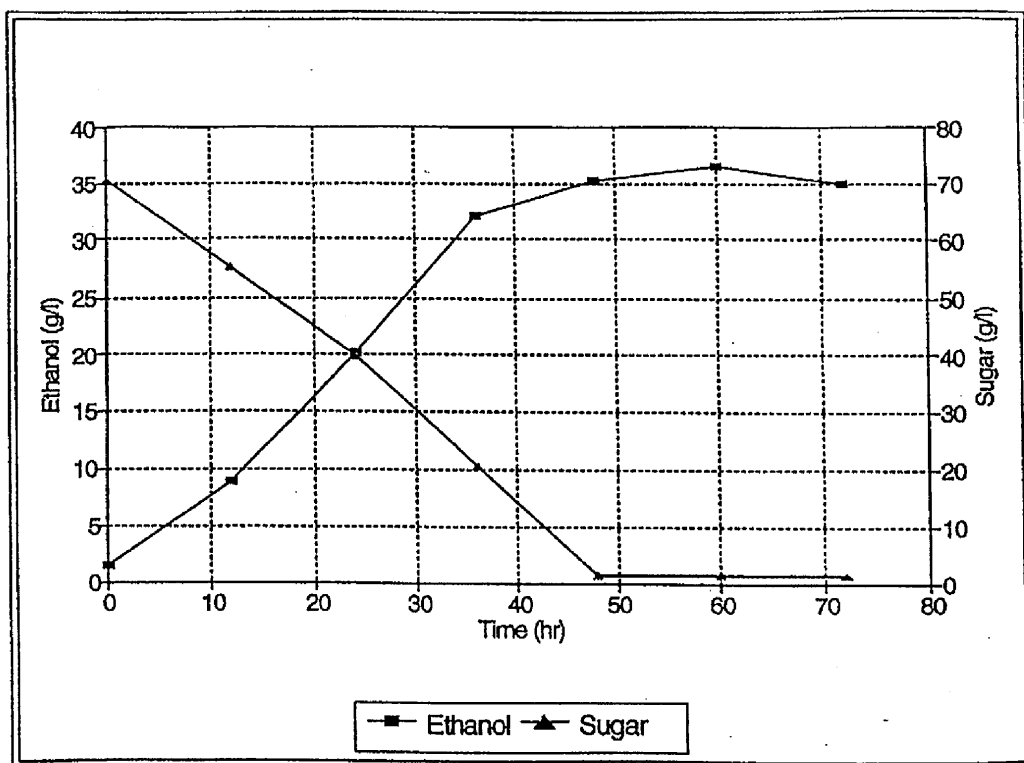


Figure 16-8. Fermentation of hemicellulose hydrolysate from sugarcane bagasse using *E. coli* strain KO11. Corn steep liquor (CSL) and crude yeast autolysate (YA) were used as nutrients.

Conclusions

Hemicellulose fractions were successfully extracted from different agricultural products with dilute sulfuric acid treatment under steam pressure. Sugarcane and elephantgrass had the highest, and leucaena had the lowest hemicellulose content. The sugar yields of the hemicellulose hydrolysis approached the maximum as determined by TSA.

E. coli KO11 can efficiently metabolize complex mixtures of sugars derived from acid hydrolysis of lignocellulosic biomass such as leucaena, elephantgrass, and sugarcane. It has been shown previously that hemicellulose hydrolysate produced from corn fiber, corn stover, sawdust, and many agricultural materials, can efficiently be converted into fuel ethanol.

Inexpensive materials such as crude yeast autolysate and corn steep liquor can be effectively used as nutrients for this organism.

This and other studies have shown that final ethanol concentration is limited by sugar concentration rather than ethanol tolerance of *E. coli* strain KO11.

Among all the samples tested, sugarcane could be the best candidate for the project in central Florida. Ethanol can be produced from extracted juice by yeasts. Then, materials are treated with mild acid to produce hemicellulose hydrolysate. BioEnergy's bacteria are capable of

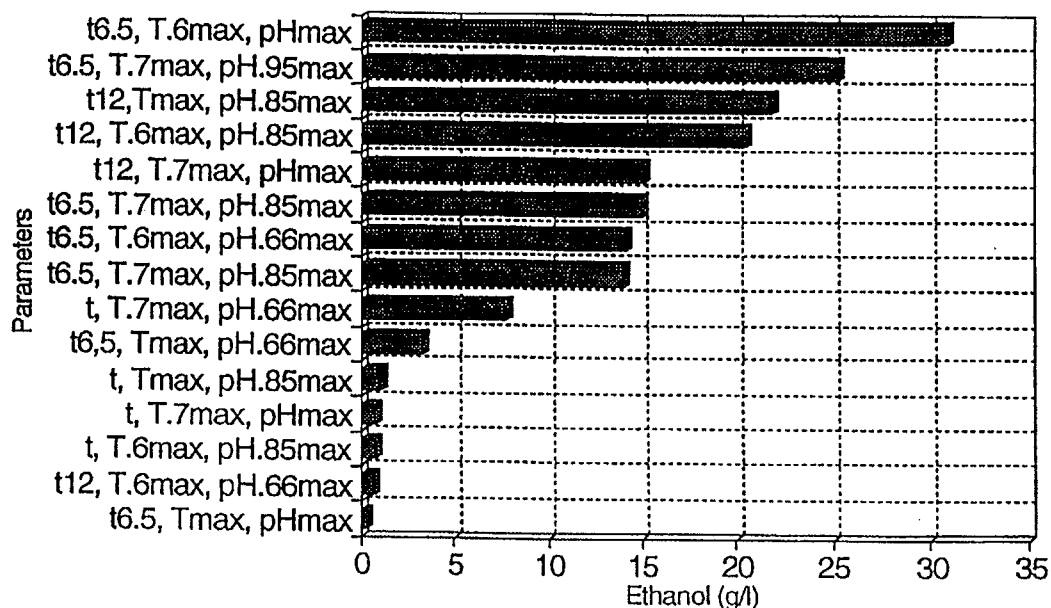


Figure 16-9. Inhibitor mitigation of sugarcane bagasse hydrolysate using hydrated lime.

producing ethanol from this syrup. The remaining cake which contains mostly lignin and partially degraded cellulose is treated with cellulase enzymes, and yeast is added to the mixture at the same time, to provide the simultaneous saccharification and fermentation (SSF process). In addition to the ethanol produced from the juice, 75-96 gal more ethanol is produced from each dry ton of sugarcane. This will drastically reduce the cost of raw materials per gallon of ethanol.

17. Direct Combustion of Biomass Materials

Phil Tuohy and Michael Juhasz¹⁸

Fuel Value of Biomass Materials

Moisture content of material tested covered a wide range from 8.7 to 69.6%. Typically Wheelabrator Ridge Energy (WRE) likes to keep moisture levels in the 30 to 40% range. Higher moisture levels in fuel results in more fuel needed to maintain proper furnace temperature. Moisture levels and BTU values for selected biomass fuels are shown in table 17-1.

BTU/lb in the biomass fuels ranged from poor to great. In general WRE finds any BTU values above 4,000 BTU/lb to be acceptable.

Ash levels (table 17-2) in the biomass fuels was very acceptable. Ash values below 10% are considered acceptable. In addition, sulfur and chlorine levels are also acceptable.

Table 17-1. Moisture and BTU Values for Biomass Fuels for Direct Combustion

Biomass Material	% Moisture	Wet BTU/lb	Dry BTU/lb	MAF ^a BTU/lb
<i>Eucalyptus</i>	57.2	3519	8221	8404
<i>Eucalyptus Amplifolia</i>	51.2	4119	8437	8715
Hydrolyzed Leucaena ^b	59.5	3258	8045	8171
Leucaena	60.0	3164	7915	8158
Leucaena (dried)	13.2	7162	8250	8494
Elephantgrass (air dried)	21.9	6073	7773	8178
Sugarcane Presscake (wet) ^c	69.6	2488	8191	8668
Sugarcane Presscake (air dried)	16.8	6384	7679	8203

^a MAF = BTU value moisture and ash free

^b Cellulose and lignin left after hydrolyzed by BioEnergy process

^c Does not appear to be practical to dry presscake normal moisture is 60-65%.

Chopped elephantgrass consisted mostly of light, fine, straw-like matter that will be burnt, for the most part, in suspension. In a power plant where a "bed" of fuel is important to proper operation, this fuel would have to be blended with other fuels. In addition, the chopped elephantgrass would not be compatible with the wood processing and wood handling system at WRE. Bridging would occur in the feeders and binding on the disk screen along with other feed problems. The most favorable quality of elephantgrass is the energy level. The more than 6,000 BTU/lb in elephantgrass is high when compared with yard waste and bagasse, which run in the 3,000 to 4,000 BTU/lb range.

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Presscake materials would be more compatible with the feed system. The presscake would handle in a similar manner to bagasse; a sugarcane by-product presently being used for fuel. On the down side, the pressed sugarcane tends to become airborne easily. Proper dust control measures will be needed to keep air pollution to a minimum.

Table 17-2. Ash, Chlorine, SO₂, and Sulfur Values from Biomass Fuels for Direct Combustion

Biomass Material	----Ash %----		----Sulfur%-----		---Chlorine %---		SO ²	Sulfur
	Rec'd	Dry	Rec'd	Dry	Rec'd	Dry	lb/mil BTU	lb/mil BTU
<i>Eucalyptus</i>	0.93	2.18	0.07	0.15	0.14	0.32	0.36	0.199
<i>Eucalyptus Amplifolia</i>	1.56	3.19	0.11	0.23	0.16	0.32	0.54	0.267
Hydrolyzed Leucaena ^a	0.62	1.53	0.15	0.38	0.02	0.04	0.94	0.460
Leucaena	1.19	2.98	0.05	0.13	0.10	0.26	0.33	0.158
Elephantgrass (air dried)	3.87	4.95	0.18	0.23	0.39	0.50	0.59	0.296
Sugarcane Presscake (wet)	1.67	5.50	0.06	0.19	0.08	0.25	0.46	0.241
Sugarcane Presscake (air dried)	5.30	6.36	0.17	0.21	0.15	0.21	0.55	0.272

^a Cellulose and lignin left after hydrolyzed by BioEnergy process

Slagging Potential of Biomass Fuels

Some concern has been expressed about the potential of biomass fuels to create deposits inside a furnace. Tests were conducted to determine the potential of these material to leave slag deposits. The test, called an ash fusibility test, (Stultz and Kitto, 1992) consists of preparing an ash sample by burning the biomass material under oxidizing conditions. The resulting ash is pressed into a mold to form a cone. The cone is heated in a furnace at a controlled rate to create a temperature rise of 15°F per minute. The furnace atmosphere is regulated to provide either an oxidizing or reducing condition. As the sample is heated, temperatures at which the cone fuses or deforms to specific shapes are recorded. Four specific deformation temperatures are recorded. They are:

1. *Initial deformation temperature* - the temperature at which the tip of the cone begins to fuse or deform.
2. *Softening temperature* - the temperature at which the sample had deformed to a spherical shape. The softening temperature is commonly referred to as the fusion temperature.
3. *Hemispherical temperature* - the temperature at which the cone has fused down to a hemispherical lump.
4. *Fluid temperature* - the temperature at which the ash cone has melted to a nearly flat layer.

When temperatures in the furnace are below the measured initial deformation temperature, most ash particles are in a dry solid state. Ash particles will bounce off of heating surfaces. If the deposit surface temperatures in the furnace are in the plastic range between initial deforming (IT) and hemispherical temperatures (HT), ash particle will tend to stick to surfaces. Wide IT to HT temperatures can result in deposits that build quickly to large proportions. If the furnace temperature is higher than the IT to HT temperature range of the fuel, furnace slagging can occur. Furnace temperatures at WRE typically run between 2,000 and 2,200 degrees F.

The reducing atmosphere temperatures of the biomass fuels in this study were close to the 2,000 to 2,200 degree F range. Moisture in the fuel also plays a role. As the moisture increases the furnace temperature decreases thus decreasing the chances of the temperature reaching the softening point.

Based on WRE's experience with burning bagasse, these fuels do not represent a slagging problem. This is true only for the present operating conditions. An increase in furnace temperature due to a change in fuel mixture, such as an increase in tire input, could make slagging an issue.

Table 17-3. Ash Fusion Temperatures (Slagging Potential) of Selected Biomass Crops for Direct Combustion

Biomass Material	Ash Fusion Temp. Reducing Atmos.				Ash Fusion Temp. Oxidizing Atmos.			
	Init Def.	Soft	Hemis	Fluid	Init Def	Soft	Hemis	Fluid
-----Degrees F-----								
Hydrolyzed Leucaena ^a	2315	2325	2345	2360	2180	2190	2205	2215
Leucaena (dried)	2520	2535	2545	2560	2545	2560	2570	2575
Elephantgrass (dried)	1915	1980	2055	2095	2100	2190	2290	2370
Sugarcane Presscake (wet)	1995	2090	2185	2220	2130	2245	2360	2435
Sugarcane Presscake (dried)	1985	2050	2160	2210	2150	2235	2350	2425

^a Cellulose and lignin left after hydrolyzed by BioEnergy process

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Project Conclusions

18 Integrated Systems

John W. Mishoe¹⁹

The objective of this part of the project was to determine a system for the production and conversion of biomass that would have the best chance of success with a minimal cost. System configuration is based upon the results and conclusions of other components and subcontracts within the overall NREL/Biomass project.

There are several major problems to overcome in planning a system. One major problem is to match the lowest cost biomass supply to the conversion system demand. In order to maintain a maximum return of the high capital cost conversion system it needs to be operated on a near continuous basis. However, biomass production is very cyclic during the year. For example, sugarcane can only be harvested three or four months during the year. Also other factors such as extreme weather events make yield and timing of biomass supply even more variable. Another problem is that the details of a number of the system components have not been designed. For example, the air drying of biomass under Florida conditions needs to be better defined. It certainly appears that it can be done, however the type of structure (if any), the effect of rainfall and the biomass losses will effect the overall cost. Perhaps of more importance to the system is the impact that cheap and reliable storage can have in reducing the cost of other components of the biomass supply curve. The third major problem is to establish the conversion technologies that will be reliable at large scale levels of operation. Through this project we have established several processes that have a realistic potential for conversion of the biomass under conditions in central Florida. Information indicates that these processes can be effectively used. However, implementation needs to be staged in such a way as to allow for development and/or modification of various operational procedures as scale-up occurs.

Integrated Systems Model

The proposed system for ethanol production is defined in figure 18-2. This system consist of several feedstocks sources that can provide a biomass source during much of the calendar year. It also consists of crops that can be harvested using similar harvesting, hauling and processing equipment. The conversion processes are established in such a way as to be able to fully utilize the biomass feedstock once the crop is produced and harvested.

An important component of the regional energy production system is presented in figure 18-1 and describes a system for production and combustion of biomass for the generation of electricity. This part of the overall system is important in two major ways. First it is a way of adding stability to our ability to use biomass once it has been harvested and cannot be used for conversion to ethanol. Waste biomass, assuming it can be air-dried can also be utilized in this process. A second major reason for needing direct combustion is that it allows other biomass sources to be used as they are available, such as pine wood. Pine is not easily converted to ethanol, however, it is a very high energy wood. Yard waste and other waste streams can also be burned that often cannot

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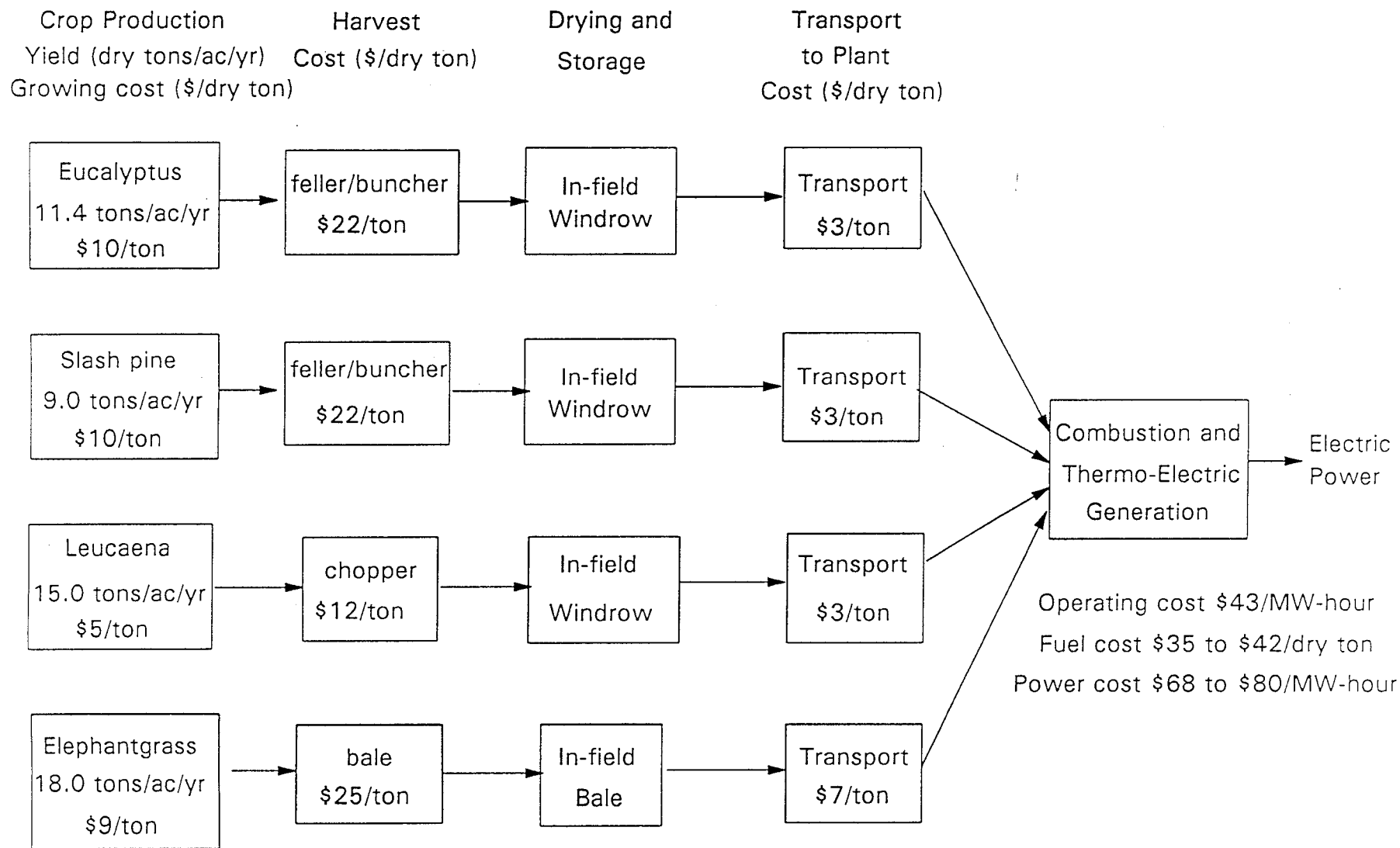


Figure 18-1. Ethanol production systems from biomass in central Florida.

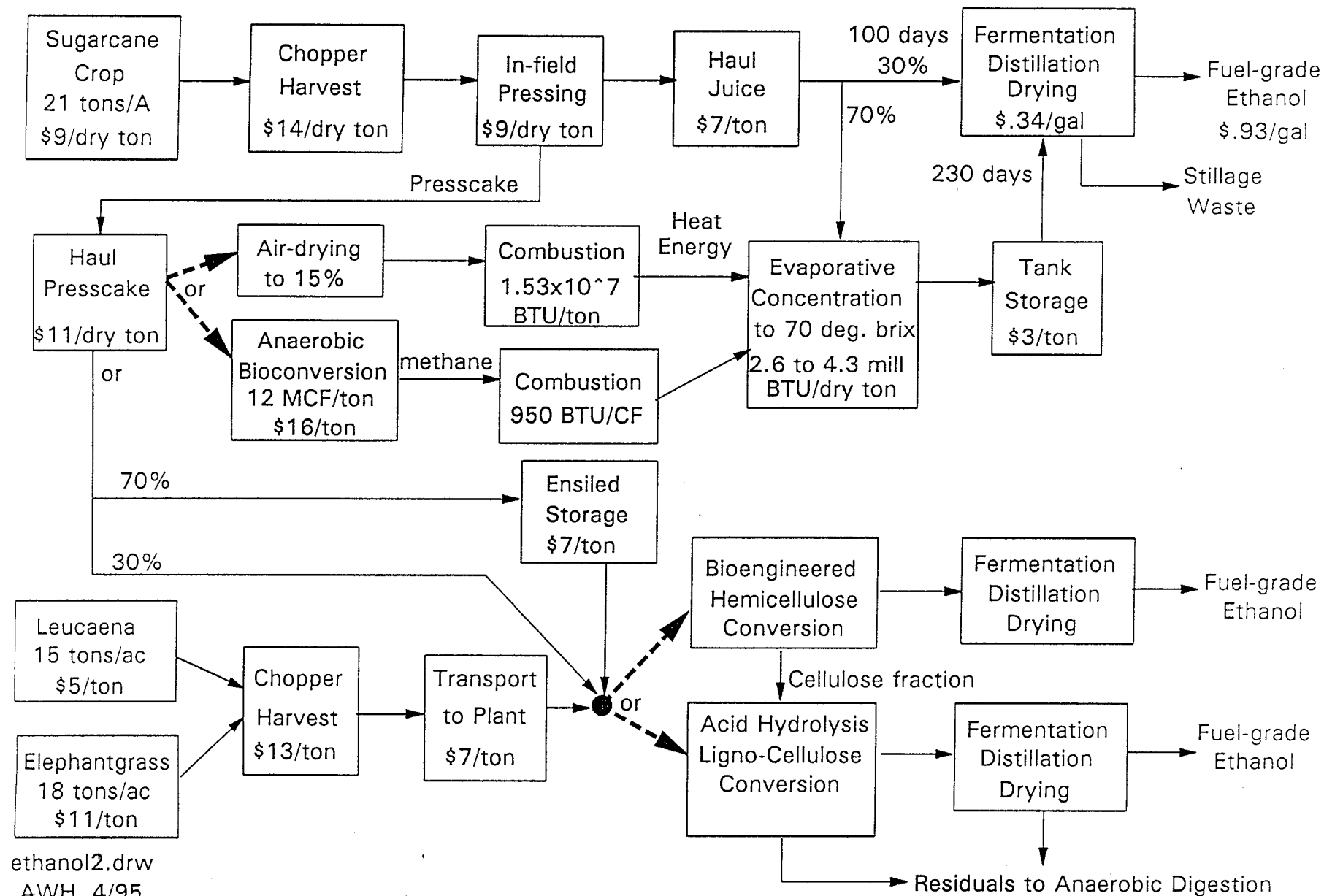


Figure 18-2. Electric power production from biomass in central Florida.

be converted using biological technologies. In the long term it becomes important to maintain this outlet for biomass that has a net energy production rather than a waste disposal problem of various biomass products.

Crop Production

Sugarcane, leucaena, and elephantgrass, represent the least cost biomass sources for these conversion processes. For sugarcane we are assuming that it can be harvested 100 days per year to produce a supply of approximately 14 degrees Brix juice. During this time, 70% of the juice will be concentrated into 70 degrees Brix juice for storage. On the flow sheet, in-field pressing of the sugarcane is assumed, however, in the long range the pressing operation may be more economically located at a central facility. The estimated cost of crop production for sugarcane is \$9/dry ton, for leucaena the cost is \$5/dry ton, and for elephantgrass the cost is \$11/dry ton. An important assumption is that the crops will be harvested with a forage type harvester. This type of harvest system has significantly lower cost than the alternatives. The cost to transport the biomass from the field to the plant ranged from \$7/dry ton to \$11/dry ton. It is also important that all three of the crops be included in the long range implementation of a system, because in part these three crops can level the monthly biomass supply curve throughout the year.

Storage

In addition to the multiple crop sources, we have included three potential methods to store biomass fuels. In the case of sugarcane, the juice can be concentrated and stored in this form for fermentation when sugarcane cannot be harvested. A second form of storage is air drying of the biomass, including the sugarcane presscake, leucaena, and elephantgrass. The assumption here is that there is a reasonable system to air dry these forms of biomass. This type of drying may only be useful for relatively small quantities of biomass. In each of these cases, after drying the biomass can then be used for direct combustion or used in the hemicellulose and/or ligno-cellulose conversion system. The third storage system can be used with the anaerobic conversion for methane or for either of the cellulose conversion systems. This system involves ensiling the presscake (or other non woody biomass) therefore reducing the need for drying of the biomass. Because storage is a relatively high cost component, it can reduce costs if this step is avoided. However, in the case of elephantgrass it may be economical to air dry the crop within the field before baling. This process would allow for storage of the large bales. In all cases we believe that storage should be minimized, however some storage will be required to maintain a reserve feedstock.

Harvesting

Harvesting is a high cost operation for these feedstocks. For the final analysis we assumed a forage chopper harvester. This system does have an advantage of producing feedstock that has similar physical properties regardless of the crop. However, it also will make in-field drying more difficult, even though materials will dry much faster than with billet or whole stem type harvesting systems. Because crop production and harvesting represent a large cost, it greatly increases the impact of biomass losses if it cannot be converted after it is harvested.

Transportation

Transportation does not represent an excessively high cost because the hauling distances are short. A major part of the cost of transportation consists of loading and unloading the biomass.

For this reason it is important that no unnecessary loading or unloading be added to the transportation system if the only purpose is to reduce overall transportation cost.

Conversion

The cost and performance of the fermentation of sugar is perhaps the best known of the conversion systems considered here. However, the potential of the hemicellulose and ligno-cellulose systems are so great that they cannot be ignored. Also, if we are to maximize the overall crop production potential of the region, we must also be able to fully utilize the various feedstock sources and be able to convert essentially all of the biomass to an appropriate form of energy.

Of course, direct combustion of the air dried feedstocks represents an important way to balance the regional biomass demand with the available supply. Two major uses of direct combustion are available as part of the options. One option is to use the air dry sugarcane presscake as a fuel source for condensing the sugarcane juice to 70 degrees Brix. As can be seen in figure 18-2, there are two options for using the residual presscake. One option is to convert the presscake to biogas (methane and carbon dioxide mixture) that can be used as a fuel source to heat the juice evaporators or as a heat source for the distillation processes. Also the presscake can be air dried and burned directly. The third option, to use residual air dried biomass, is as a fuel source for electrical generation. Currently excess biomass and other waste fuel sources are being used at local generating facilities for direct generation of electricity.

Drying of the biomass may be a more difficult task than implied in the above discussion. Perhaps a better system than air drying the biomass is to use forced hot air drying (or similar heated drying) rather than simple unforced air drying. The energy content of wet presscake (70% moisture) is approximately 2500 BTU/lb. This represents a net energy yield which could be useful. The energy yield of 15% moisture presscake is greater than 8000 BTU/lb. With the presscake supply available from the pressing operation there is enough energy to concentrate the juice and then supply at least part of the energy necessary to dry the presscake. Also the cellulose by-product of the hemicellulose and ligno-cellulose conversion system is a possible fuel source with properties, including energy content, similar to that of the sugarcane presscake. With these combined biomass sources, heated drying and then direct combustion of the biomass represent an energy source that will improve total utilization of the energy content of the biomass. This area needs to be researched in more detail.

The ultimate goal is to convert presscake and other biomass materials to ethanol by using a series of conversion processes. The first would be to convert the hemicellulose fraction, using the Bioengineered conversion system. The next step would be to convert cellulose by the NREL acid hydrolysis process to ethanol. Because these two processes need to be scaled up in such a way as to be able to optimize each component as technology is developed, alternate processes such as the direct combustion represent an important component to the overall efficiency of the system.

19 Optimum Systems

John W. Mishoe

In the strict sense we are not able to determine a true optimal system configuration. However we can provide a reasonable and perhaps feasible solution to the overall system. Based upon the economic analysis we have a reasonable estimate of the cost of most of the major system components. Perhaps the cellulose conversion systems are the least precise because in part we do not have experience with large scale systems. Our analysis, however, indicates that our proposed system can be economical and profitable in the long term. As the business plan presents below, start up will certainly have a negative cash flow. A phased implementation of the system is the only reasonable way to approach the development. Phase one of the implementation should consist of a juice pressing operation, a fermentation system, and a system for using the presscake. Also, additional feedstock can be purchased to maintain the fermentation plant on a year round basis and sugarcane juice can be process initially during the harvest season only. During the first year the residual presscake can be used as a start up fuel source for the cellulose conversion systems.

As part of the start-up, leucaena and elephantgrass crops can be established, with the fuel used for electrical conversion until it can be used in the bioconversion process for ethanol.

From this starting point various components of the system can be brought on line as time allows. The staged development of the system will be controlled to some extent by the systems that are currently in operation within the area. For example Bartow Ethanol or Mulberry Ethanol can be a site to begin the fermentation plant using existing facilities. Because there is an advantage of having all conversion components in close proximity, expansion may need to consider site characteristics. Lowest cost conversion will be achieved by sharing common components such as dryers or distillation columns.

20 Preliminary Business Plan

John F. Gerber²⁰

Executive Summary

UF/NERL Biomass to Ethanol, Inc. is the name used for a proposed company to be formed to produce biomass and convert it to fuel ethanol by fermentation of sucrose juice from sugarcane. This will be followed by the hydrolysis of the hemicellulose in the presscake and the fermentation of the sugars released to ethanol with genetically altered bacteria capable of fermenting hemicellulose derived sugars. The ability to ferment both the sucrose and the hemicellulose sugars is the unique feature of this technology and forms the basis for the business. The biomass production and the subsequent ethanol production is based on data and technology developed in a research project performed by the University of Florida and its subcontractors working under a contract from the National Renewable Energy Laboratory (NERL). The purpose of this project was to identify the land, the biomass crops and the ethanol conversion technology which has the economic potential for the development of a company dedicated to production of a biomass energy crop. During this project, five crops were identified which have the best potential to form the basis of a viable biomass energy business. These crops are: sugarcane, elephantgrass and leucaena (a woody specie) along with *Eucalyptus* and pine.

All these crops can be grown on reclaimed lands which have resulted from phosphate extraction, and include settling ponds with high clay content. The costs of producing and harvesting these crops based upon test plot data is estimated to be between \$15 and \$30 per dry ton. The annual yields based upon 10 years of data are between 15 and 25 dry tons per acre. The first ethanol plant is estimated to produce between 70 and 80 gallons per dry ton of sugarcane with the residue being used to power the plant or marketed for electricity production.

The company will demonstrate feasibility in the first phase by conversion of significant tonnage of material to ethanol in an existing ethanol plant while developing the agronomic, harvesting, and engineering requirements, juice extraction, and hemicellulose hydrolysis. The sucrose will be fermented with yeast using existing technology. The hemicellulose derived sugars which are largely unfermentable by yeast will be fermented to ethanol with novel genetically altered bacteria.

The second phase will involve funding, designing and construction of a demonstration plant capable of producing from 1 to 5 million gallons of ethanol per year. This would prove the biomass production, harvesting and conversion of the hemicellulose to ethanol. The planned corporation may initially be a private/public corporation to fund initial feasibility, and charged with the formation of a private corporation or cooperative to construct the demonstration plant and subsequently full scale plants, in the third phase.

The demonstration plant is anticipated to be a hybrid corn (or waste stream)/biomass plant in which the biomass will be utilized seasonally, and the corn when biomass (or waste material) is not available. This will also develop competency in the conventional processes, allow market entry, generate a revenue stream and form the basis for entry into the ethanol market.

The current project leader, Mr. James Stricker, has indicated an interest and willingness to be the organizer of the first phase, feasibility study and has significant knowledge and experience in the production of biomass on mined lands.

The Polk County Mined Lands Agricultural Research/Demonstration Project, headed by Mr. Stricker, has almost 10 years research experience growing crops on reclaimed phosphatic clay soil. Biomass crops have been part of the crop mix included in the research. Acreage of planting materials for these crops have been scaled up as part of this project.

The state of Florida does not have a small producers incentive program, but ethanol prices in Florida are usually slightly higher than in the midwest. At least 2 ethanol plants are in existence near Bartow, and a third is planned. One of these plants is a potential cooperator for the first phase. This phase will be based on sugarcane with an objective of producing sufficient biomass to supply the feedstock to an existing ethanol plant for 1 month. Both conventional fermentation and pentose fermentation will be preformed. The cooperating plant will share in profits from the sale of ethanol and from the reduced cost of the feedstock, and in addition, would market the ethanol produced in return for the use of equipment and modifications which might be required for the performance of the test. In exchange the cooperator would be granted a preferred participant position for the phase two demonstration plant.

Company History

Description of UF/NERL Biomass to Ethanol, Inc. - UF/NERL Biomass to Ethanol, Inc. is the name used for a development corporation to be organized to exploit the technology and information base developed jointly for the production of energy from biomass produced in Florida on low value lands which are the result of phosphate mining in central Florida. Mr. James Stricker will assume the primary leadership responsibility for the organization and development of the corporate structure of the corporation known hereafter as the Corporation. This Corporation may be a public/private consortium of Universities, Government Labs and private companies or cooperatives. Mr. Stricker will focus the various interests and efforts required to plan, finance, organize and operate a three phase development process consisting of:

- * Phase I. The production, harvesting, juice extraction and hemicellulose hydrolysis of enough sugarcane to supply feedstock for 30 days ethanol production in a local ethanol plant.
- * Phase II. The design, construction, financing and operation of a demonstration plant producing from 1 to 5 million gallons of ethanol utilizing sugarcane and corn in a hybrid plant in which at least 100 days of operation will be based on the exclusive use of sugarcane as the feedstock.
- * Phase III. The design, construction, siting, biomass production contracts, and operation of an ethanol plant producing ethanol from biomass for at least 200 of the 300 annual days of operation. The biomass feedstocks are expected to consist of sugarcane, elephantgrass, leucaena, and *Eucalyptus*. The ethanol production of the plant will be at least 10 million gallons per year.

Products and Technology

Products - The products of this business include the production of a biomass energy crop that is converted to either fuel ethanol or burned to generate electricity. The goal is to demonstrate

an economically viable biomass to ethanol business. There are two basic components of the business the production of biomass on land which is currently of little or no agricultural value and the conversion of the biomass produced on this land to energy either in the form of ethanol, electricity, or both. The biomass will be a combination of up to four crops. Sugarcane, elephantgrass, leucaena, or *Eucalyptus*. The choice of these crops is based upon extensive research by The University of Florida, Institute of Food and Agricultural Sciences. The land which will be used is either clay settling ponds or overburden from the phosphate mining activities in central Florida. This land, especially the clay settling ponds has little value except for agricultural purposes since it is extremely difficult to de-water and for many years has been viewed as being of no or negative economic value. This land is owned by various companies including the phosphate mining companies, but can be leased at nominal cost. It is estimated that 73,000 acres are available in central Florida. This land is composed of 37,000 acres of de-watered clay settling ponds, and 36,000 acres of mined out areas.

The four crops were chosen based on the high dry matter yields and low cost of production. Data on yields and production costs are shown in other sections of this report. Ethanol yield per ton of presscake and elephantgrass are based in part on data in the reports from BioEnergy on extensive work with similar biomass and commercially produced bagasse. Sugarcane produces the highest yields, but leucaena is the cheapest to produce and harvest. The cost to produce and harvest these crops is estimated to range from \$15 to \$23 per dry harvested ton. The material would not be dried but would be at field moisture and would be harvested by field chopping.

Fuel ethanol is the primary final product, with residual biomass and CO₂ being secondary products. The CO₂ will be sold to CO₂ business and the residual biomass will be either burned to produce steam and electricity for the ethanol plant or sold to power generating plants as fuel based on the BTU value per pound which is approximately \$10/ton. Ethanol is splash blended with gasoline to add oxygenates and increase octane ratings. It is also used to produce ETBE an oxygenate that is used to meet air quality standards and to increase octane ratings. Approximately 1 billion gallons of ethanol are produced in the U.S. each year for use with gasoline to meet air quality and octane standards. Ethanol has been used for 20 years in the U.S. for this purpose and several million light trucks and autos are powered by neat ethanol in Brazil. Despite minor problems and some predictions of corrosion problems, ethanol has proved to be a highly desirable auto fuel with both environmental and octane advantages. The environmental advantages extend beyond the improvement in air quality to safety in handling and the complete biological degradation of any spills that may occur.

Technology description - The technology which will be used is a phased implementation with the incorporation of well established technology; the fermentation of sucrose and glucose to ethanol with yeast and the fermentation of pentoses derived from hemicellulose to ethanol with genetically engineered bacteria either *E. coli* KO11 or *Zymomonas mobilis* modified to ferment xylose and hexoses.

The technology of fermentation of juices expressed from sugarcane is well established. The technology used will express the juice by screw pressing chopped whole cane either in the field or at the ethanol plant. At least 85% -90% of the sucrose will be extracted and concentrated to 12 to 14 degrees Brix-12% to 14% sucrose. This juice will be fermented conventionally producing 6% to 7% ethanol (w/w) basis. The presscake or bagasse as it is termed in the sugarcane industry will be cooked with dilute strong acid-pH 1.0- at 140°C for 30 minutes. If the proper solids ratio is maintained, more than 90% of the hemicellulose will be hydrolyzed and will produce a syrup containing 60 to 80 g/L of mixed hexose and pentose sugars along with solubilized acetic, lactic, glucuronic, xyluronic, and other mixed phenolic acids. During the

cooking process approximately 1/3 of the solids will be solubilized leaving a solid residue of cellulose and lignin. These residues can be reduced to 50% solids by passage through a screw press. The cooked cake must be washed to remove at least 90% of the sugars. The syrup will be concentrated to 100 to 120 g/l of total mixed sugars. Brix are not a reliable measure of sugars in these syrups because other components produced during the cooking process contribute to the refractive index and will produce Brix reading which are higher than the sugar content. These syrups must be treated to mitigate the inhibitors and then fermented with the bacteria. KO11 will ferment these sugars to 5% to 6% ethanol in 60 hours with at least 90% of theoretical efficiency using nutrients based on corn steep liquor and supplemented with materials such as crude yeast autolysate.

The technical plan is to demonstrate engineering and technical feasible by producing enough sugarcane to provide one months feedstock to a small existing ethanol plant. During the remainder of the year the plant would use corn, waste materials, or other conventional feedstocks.

The sugarcane will produce approximately 480 pounds of sucrose per dry ton of cane, and 490 pounds of presscake. The sucrose will produce 65 gallons of ethanol per ton and the hemicellulose in the cake will produce 18 gallons of ethanol per dry ton of harvested cane. Together the sugarcane will produce 83 gallons of ethanol per dry ton and 640 pounds of fuel. The value of the ethanol will be \$100/ton and the fuel will be worth \$3.20/ton. Each acre of sugarcane will produce \$2,270.20 of revenue exclusive of any value for CO₂ produced. About 5.4 tons of CO₂ will be produced worth at least \$25/ton in Florida.

Competition

Corn to ethanol - The primary competition is ethanol produced from corn by either wet or dry milling. In wet milling the excess corn syrup is fermented to ethanol with yeast. The other by-products reduce the feedstock cost so that the cost of the corn per gallon of ethanol produced is less for wet millers than for dry millers.

Wet millers produce CO₂ and corn gluten feed as by products. Much of the corn gluten feed is marketed in Europe for cattle feed. There is some uncertainty about the future demand and price for corn gluten feed. Dry millers grind corn, cook it and add enzymes and ferment it with yeast in an SSF process. The by-products are CO₂ and DDGs. Each bushel of corn processed produces 2.5 gallons of ethanol and an equal weight of CO₂. The still bottoms and spent yeast are combined in the DDGs. About 17 pounds of DDGs are produced which generally demand higher prices than corn gluten feed. After subtracting the value of the DDGs, the cost of the corn feedstock per gallon of ethanol is between \$0.40 and \$0.50 per gallon depending upon the price of corn and DDGs.

Since ethanol is a commodity, the price fluctuates with supply and demand. For a biomass to ethanol business to succeed, the price of the feedstock per gallon must be less than that for corn from the dry milling process, since the biomass handling and processing will be more expensive than for corn.

Alternative fuels - There are a number of alternative fuels which compete with ethanol. Most of these are neat or pure fuels with the exception of oxygenates such as MTBE. The main alternative fuels are compressed natural gas, methanol, and propane. As long as ethanol is used as an additive for oxygenation and octane, the alternative fuels will not be likely to impact heavily on ethanol demand.

The Market

The market for ethanol in the U.S. is now about 1 billion gallons per year. There is some expectation that this market will increase if ethanol is mandated to have a percentage of the oxygenate market. Even without these mandates there is an expectation that the demand will increase. MTBE has been attacked for alleged health effects which is likely to increase the demand for ethanol as ETBE production is increased. On the longer term, it appears that the demand for petroleum based products in Asia will significantly increase during the next decade and will probably escalate the domestic U.S. gasoline prices and make ethanol more price competitive.

The U.S. market is dominated by ADM, New Energy, Pekin Energy, Cargill, A.E. Staley with other newer smaller plants gaining market share. Most of the ethanol produced in the U.S. is produced by ADM. Almost all of the current U.S. production is from the fermentation of starch in cereal grains. No commercial production of ethanol from biomass exists in the U.S.

Market Strategy

It is UF/NERL Biomass to Ethanol, Inc. intention to develop the biomass to ethanol technology and to market this by the construction of full scale plants utilizing this technology. There is no intention to market the technology to other ethanol producers at this time.

Plan for development

Planning the development - Mr. James Stricker, Polk Co./Univ of Fla. Extension Agent, has been involved in the production of biomass from mined phosphate lands for the past 8 years. During this time he has provided leadership to an effort which has produced excellent data on the biomass production potential of mined phosphate lands. The data which has been generated indicate that 15 to 25 tons of dry biomass can be produced on a sustained basis. This biomass can either be converted to ethanol, burned for power generation or used for both purposes by first extracting useable fermentable sugars and then burning the remaining residue for power. Mr. Stricker has been the focal point for this effort. Further biomass research and development requires the production, harvesting, and conversion of large quantities of biomass so that the technical and engineering data can be generated that will support the design and operation of a demonstration plant.

Business Strategy - The business strategy is to form a consortium of public and private organizations which have a vested interest in the use of mined lands and in the production of ethanol and/or power from crops grown exclusively for biomass energy production. This consortium will be organized into the Corporation that will fund and operate Phase I. A budget will be made for Phase I with in-kind and cash contributions made by the participants for the entire Phase I. In addition, a Private for-profit corporation or cooperative will be formed to conduct Phase II and Phase III. Public and government participation in Phase II and Phase III will be available through contracts from specific parts of the technology and business development.

It is unlikely that Phase II will be profitable, but it may be break-even and allow formation of significant technical know how. Funding will be by equity investments by the private participants in phase I with the remainder as debt equity. Phase III will be profitable with returns to investors, see (Pro Forma).

Financing

1. Cash

In order to carry out this business plan it will be necessary to generate enough cash to organize the business and purchase services and items which can not be obtained through in-kind goods and services. Cash will be sought from the following sources:

- a. Existing grants which may be in place or which may be extended or modified for the purposes outline in Phase I.
- b. Federal funds in the form of grants, contracts, SBIRs or other assistance vehicles to be identified.
- c. State and county funds such as Enterprise Florida, Phosphate Industry Supported organizations and county, regional and local funds.
- d. Equipment and engineering firms that might participate in the design and construction of future plants.
- e. Land owners that may derive income from land used to produce biomass.
- f. Phosphate industry either individually or small consortium that are involved in land restoration or have significant holdings of settling ponds and overburden land.
- g. The Investment community that may be interested in investment opportunities in large scale production of ethanol from biomass in Florida.

2. Contributions "in-kind"

In-kind contributions will constitute a major portion of the needed support for Phase I. There is too little detailed information to make specific estimates of the value of this support, but the following items and services have been identified as areas where "in-kind" support may be available.

- a. Harvesting equipment.
- b. Cane juice extraction equipment.
- c. Hydrolysis equipment.
- d. Engineering design.
- e. Financial services.
- f. Land rental.
- g. Seed sources.
- h. Cultivation and planting equipment.
- i. Crop management information and advice.

Specific Phase I Issues

1. Land availability

One of the tasks in the NERL sponsored project was to identify land resources and availability. Approximately 73,000 acres were identified as being available, largely from general information. It will be necessary to establish agreements and commitments with land

or lease holders for the use of land for biomass production. A certain amount of land is available through existing research projects and may be sufficient for Phase I. According to the best estimates 240 to 280 acres should be sufficient to produce a 30 days supply of sugarcane.

2. Ethanol plant cooperator

There are two ethanol plants in the immediate Bartow, Florida vicinity. They are Bartow Ethanol and Mulberry Ethanol. Bartow Ethanol has not been in operation for several years, but is currently retooling and expects to be in operation within the year. Mulberry Ethanol is a new dry milling plant which will commence operations in 1995. Both plants would be capable of fermenting sugarcane juice containing sucrose, but would need either modifications and additional equipment to hydrolyze the hemicellulose in the presscake and ferment the hemicellulose derived sugars with the genetically altered novel bacteria.

3. Production of biomass

Phase I entails the production of a 30 day supply of sugarcane biomass and the subsequent harvesting, juice extraction, hemicellulose hydrolysis and fermentation of the sugars to ethanol.

This 30 day operational period will require careful coordination for the planting and cultivation of the crop and careful coordination during the harvesting, and subsequent conversion to ethanol to insure that all components are working properly and that all the needed technical, logistic and engineering data are collected.

The present plan is to produce the biomass on clay settling ponds, harvest the cane by field chopping, expressing the juice in the field, concentrating the juice to at least 20° Brix, transporting the expressed juice to the ethanol plant for fermentation, transporting the presscake to the plant site for hydrolysis by cooking with dilute strong acid and then fermenting the hemicellulose sugars to ethanol with novel genetically altered bacteria.

The following tasks have been identified and must be conducted in some order similar to the order listed.

a. Producing the biomass

1. Locating available land.
2. Locating cane seed sources.
3. Locating planting equipment.
4. Planting the crop to coincide with harvesting times.
5. Arranging for pest management and fertilizer and other cultural requirements.

b. Harvesting the crop

1. Locating and securing the machinery capable of field chopping the cane.
2. Arranging for the field transportation of the chopped cane.
3. Arranging for the "in field" extraction with screw presses and determining the number of passes and number of presses required to supply the ethanol plant.
4. Arranging for the transportation of the presscake to the hydrolyzer site.

c. Fermentation and hydrolysis of the cane juice and presscake

1. Finding an ethanol plant cooperator and scheduling the fermentation of the sucrose juice.

2. Securing a hydrolyzer to cook the presscake and release the hemicellulose sugars.
 3. Securing the novel bacteria and the technology required to ferment the hemicellulose sugars.
 4. Securing data on the fermentation and yield of ethanol from both the cane juice and the cooked syrup.
- d. Health, safety and environmental issues
1. Securing the necessary permits to use the novel organism(s).
 2. Training the operators of the equipment to insure safety.
 3. Verifying the existence of all water and air permits.
 4. Insuring the containment and destruction of the novel bacteria at the conclusion of the trial operational period.
- e. Financial and management
1. Insuring that the necessary financial commitments are in place prior to commencement.
 2. Coordinating the operations.
 3. Keeping interested parties informed and conducting public information programs on the effort and working with interested public affairs and environmental groups.

Phase II Demonstration Plant

After careful examination of the available data, it became apparent that graduated step-wise entry into the biomass ethanol business was less risky and more logistically and financially practical. For Phase II we selected a hybrid plant that combines a conventional dry milling corn to ethanol plant with two biomass feedstocks-sugarcane and elephantgrass. The plant will operate for 100 days each year with sugarcane being the exclusive feedstock. For an additional 230 days it will operate with corn and elephantgrass feedstock. The size planned is 5 million gallons per year. These choices were made based upon the cost of the feedstock per gallon of ethanol and the necessity to utilize the equipment as fully as possible. The hemicellulose hydrolyzer will be sized on the basis of that required to process the sugarcane presscake when the plant is utilizing sugarcane at a rate that will produce 5 million gallons of ethanol per year. This will require 177 dry tons of cane per day and 800 to 1,000 acres of sugarcane.

The elephantgrass will be processed at the rate of 89 dry tons per day for 230 days. The result is that the same tonnage of dry presscake and elephantgrass will be hydrolyzed daily. The data for the elephantgrass hemicellulose and ethanol yield are not as precise as is needed and further work on hydrolysis and conversion needs to be done during Phase I, so that better estimates of needed acreage can be made. This is not a serious problem since any loss of ethanol yield from the elephantgrass can be made up with more corn. On the basis of the best data available, 1,000 to 1,200 acres of elephantgrass will be needed.

The planned plant will produce 1.5 million gallons of ethanol per year from sugarcane, 750,000 gallons from elephantgrass and 2.75 million gallons from corn. In addition, 9,400 tons of DDGs, 14,800 tons of CO₂ and 19,300 tons of biomass fuel would be produced. Using the same amount of biomass produces a continuous supply of fuel if the plant were to be powered by the biomass residue. The estimated net feedstock cost per gallon would be \$0.14 for sugarcane, \$0.40 for elephantgrass and \$0.50 for corn. These estimates are based upon the data supplied from the NERL/UF project and are \$21.71 per dry ton for field chopped sugarcane, \$23.42 per dry ton for field chopped elephantgrass, and \$2.50 per

bushel for corn. There would be no storage of sugarcane. Storage of elephantgrass will be either dry or as silage.

The total revenues for this plant should be approximately \$8 million if the CO₂ is sold for \$25 per ton and if the fuel is sold for \$10 per dry ton. The selling price of ethanol was assumed to be \$1.25 per gallon and prices of DDGS were assumed to be \$125 per ton.

1. Selling the Products

Ethanol will be sold either on the local spot market or under contract to blenders, or ETBE manufacturers. A part of the planning for Phase II will be securing contracts or long time commitments for the sale of ethanol.

DDGS will be sold locally if possible. There should be a market for the DDGS in the dairy industry. It may be possible to sell the DDGS in a moist condition rather than dried, which will reduce the cost of drying. Since the DDGS will not be available all the time it may be necessary to dry and store them in order to obtain long term commitments.

Carbon dioxide is not as plentiful in Florida than in other regions of the U.S. Carbon dioxide may be marketable in un-compressed form to marketers and producers of CO₂. Selling over the transom to a compressor/marketer may be the least expensive and most economically attractive alternative. Unless markets are strong, the 5 million gal plant may not produce enough CO₂ to make, capture, and marketing economically attractive. Carbon dioxide is used in the food processing and carbonated drink markets.

2. Financing Phase II

a. Demonstration Plant

1. Financing of the demonstration 5 million gallon per year plant will probably be a combination of equity and debt capital. It is hoped that the equity will be contributed by interests that hold assets whose's value will significantly increased by the data and engineering experience obtained with the plant. These equity holders may be land owners, equipment manufacturers, investment bankers or ethanol producers. In order to make the project viable and economically attractive, future proprietary rights to the data, technology and processes may be exchanged for invested equity.

2. Engineering Design and Construction.

a). Process design will be the first key feature to be completed for the Phase II demonstration plant. This will be a combined effort between an Engineering Firm, providers of technical data and equipment manufacturers.

b). Engineering design will be performed after the basic process design is developed and agreement is reached on the basic components and feedstocks. The firm selected will be responsible for the entire design and may have the overall responsibility for design and construction.

c). Construction

3. Biomass Production and Feedstock Contracts

a. Sugarcane production may be carried out under contract with land owners or with producers who will provide the land through contract and will agree to produce the cane in

5. Pro Forma

Table 20-1. Ethanol Pro Forma for Phase II Demonstration Plant Year 1 Based on A Combined Sugarcane, Elephantgrass, and Corn Ethanol Plant - Total Ethanol Produced: 5 Million Gallons Annually

	Corn		Sugarcane		Bagasse		Elephantgrass		Facility Total	Total \$/Gal
	Plant Amount	Plant \$/Gal	Plant Amount	Plant \$/Gal	Plant Amount	Plant \$/Gal	Plant Amount	Plant \$/Gal		
Gallons	2,745,312		1,187,216		327,935		739,537		5,000,000	
Revenues:										
Ethanol Sales	3,603,222	\$1.25	\$1,558,221	\$1.25	\$430,415	\$1.25	\$970,642	\$1.25	\$6,562,500	\$1.25
DDG Sales	\$1,166,758	\$0.40							\$1,166,758	\$0.23
Excess Fiber or Energy		\$0.00			\$90,690	\$0.26	\$208,587	\$0.27	\$299,277	\$0.06
CO ₂ Revenue	\$203,839	\$0.07	\$88,151	\$0.07	\$24,349	\$0.07	\$54,911	\$0.07	\$371,250	\$0.07
Total Revenue	\$4,973,819	\$1.72	\$1,646,372	\$1.32	\$545,454	\$1.58	\$1,234,140	\$1.59	\$8,399,785	\$1.61
Cost of Sales:										
Labor	\$274,531	\$0.10	\$118,722	\$0.10	\$32,794	\$0.10	\$73,954	\$0.10	\$500,000	\$0.10
Feedstock	\$2,745,312	\$0.95	\$196,888	\$0.16	\$196,888	\$0.57	\$488,511	\$0.63	\$3,627,600	\$0.69
Chemicals and Supply	\$322,967	\$0.11	\$139,668	\$0.11	\$50,317	\$0.15	\$113,471	\$0.15	\$626,423	\$0.12
Energy	\$358,564	\$0.12	\$77,531	\$0.06	\$17,522	\$0.05	\$39,513	\$0.05	\$493,130	\$0.09
Maintenance	\$88,431	\$0.03	\$35,616	\$0.03	\$26,235	\$0.08	\$59,163	\$0.08	\$209,455	\$0.04
Waste Disposal	\$27,453	\$0.01	\$11,872	\$0.01	\$6,559	\$0.02	\$14,791	\$0.02	\$60,675	\$0.01
Total Cost of Sales	\$3,817,258	\$1.32	\$580,297	\$0.47	\$330,315	\$0.97	\$789,403	\$1.03	\$5,517,283	\$1.05
Gross Profit:	\$1,156,561	\$0.40	\$1,066,075	0.85	\$215,141	\$0.61	\$444,737	\$0.56	\$2,882,502	\$0.56
General Administration	\$81,500		\$81,500						\$163,000	\$0.03
Insurance	\$61,596								\$61,596	\$0.01
Depreciation	\$457,552	\$0.37	\$197,869	\$0.16	\$65,587	\$0.19	\$147,907	\$0.19	\$818,954	\$0.16
Interest Expense	\$390,864	\$0.31	\$169,030	\$0.14	\$56,028	\$0.16	\$126,350	\$0.16	\$699,591	\$0.13
Property Taxes	\$13,795	\$0.01	\$5,966	\$0.00	\$1,977	\$0.01	\$4,459	\$0.01	\$24,691	\$0.00
Royalties	\$0.00	\$0.00	\$0.00	\$0.00	\$13,117	\$0.04	\$29,581	\$0.04	\$72,280	\$0.01
Total Expenses	\$1,005,307	\$0.69	\$454,3650	\$0.30	\$136,710	\$0.40	\$308,297	\$0.40	\$1,840,112	\$0.34
Earnings Before Tax	\$151,254		\$611,710		\$78,431	0.21	\$136,440	0.16	\$1,042,390	\$0.22
Taxes	\$52,939		\$214, 98		\$27,451		\$47,753		\$362,544	
Less Small Producer Tax Credit	\$118,722	\$0.10	\$32,794	\$0.10	\$73,954	\$0.10	\$274,531	\$0.10	\$500,000	\$0.10
Total Taxes	(\$65,783)	\$-0	\$181,305	(\$0)	(\$46,503)	(\$0)	(\$226,778)	(\$0)	(\$137,456)	\$0.00
Net Income	\$151,254	\$0.00	\$611,710	\$0.00	\$78,431	\$0.00	\$136,438	\$0.00	\$1,042,399	
Cash available (Net+Dep)	\$608,806		\$809,579		\$144,018		\$284,345		\$1,861,353	

Table 20-2. Financial Summary From Pro Forma

Financial Summary Phase II Plant	
Cash Available	\$1,861,353
Return on Invested Equity	43.28%
Payment (P&I)	\$1,051,584
Interest	\$699,591
Summary after Principal Payment	
Cash available	\$1,509,360
Net Return to Invested Equity	35.09%
Remaining Invested Equity	\$2,791,773

Table 20-3. Assumption Table for Pro Forma

Assumption Table	Corn	Sugarcane		Elephantgrass	Facility total
		Juice	Presscake		
Phase II Demo Plant	Bushel	Dry ton	Dry ton	Dry ton	
Ethanol Yields (gal.)		65.45	36.16	35.45	
Cost (dry)	\$2.50	\$10.86	\$21.71	\$23.42	
Cost (\$/year)		\$196,888	\$196,888	\$488,511	\$882,288
Fuel \$/Dry Ton			\$10.00	\$10.00	
Fuel \$/Year			\$90,690	\$280,587	\$299,277
Yield (tons/acre/yr)		22		18	
Ton Fuel/Dry Ton	0.00	0.00	0.33	0.66	
Value Fuel \$/Dry Ton			\$3.25	\$6.60	
Dry Tons/Day		181	91	91	91
Dry Tons/Hour	0.00	7.56	3.78	3.78	3.78
Acres/Year	1,098,125	824		588	
DDG (\$/ton)	125.00				
DDG (pounds/bushel)	\$17.00				
DDG (\$/bushel)	\$1.06				
Days/Year	230	100	100	230	330
Ethanol (gal/yr)	2,745,312	1,187,216	327,935	739,537	5,000,000
Ethanol (gal/day)	11,936	11,872	3,279	3,215	15,152
Ethanol Price (\$/gal)					\$1.25
Denaturant Gasoline (\$/gal)					\$0.70
CO ₂ (tons/year)	8,154	3,526	974	2,196	14,850
CO ₂ Price (\$/ton)					\$25.00
CO ₂ (\$/year)	\$203,839	\$88,151	\$24,349	\$54,911	\$371,250
Corn Steep Liquor (\$/ton)					\$55.00
Sulfuric Acid (\$/ton)					\$50.00
Capital (\$/gal)	2.50	2.50	3.00	3.00	
Equity	0.33	0.33	0.33	0.33	\$4,301,133
Total Capital	\$6,863,280	\$2,968,040	\$983,806	\$2,218,610	\$13,033,736
Debt	\$4,598,398	\$1,988,587	\$659,150	\$1,486,469	\$8,732,603

35
1.25
~44

specified quantities, qualities and prices. Since sugarcane can be grown as a perennial crop, the contracts may be multiple year contracts, or annual with renewal clauses.

b. Elephantgrass production will be carried out under contract with land owners or with a producer who will provide the land through contract and will agree to produce the elephantgrass in specified quantities, qualities, prices and delivery schedules. Since elephantgrass is a perennial crop, the contracts may be multiple year contracts or contain annual renewal clauses.

c. Corn is a commodity traded on commodity markets. Corn contracts or contracts for supply at prices tied to midwest prices may be made with specified quality, delivery schedules, and quantities at the plant.

6. Licenses.

The novel bacteria can either be *E. coli* KO11 to be licensed from BioEnergy International, L.C. or the genetically altered *Zymomonas mobilis* licensed from NERL. These licenses will add some extra cost to the production cost of all ethanol manufactured using the bacteria. The estimate is not more than 4% of sales of the ethanol made with the bacteria.

7. Operation

Operation of the demonstration plant will require the recruitment, training, and retention of a management, technical and operational team.

8. Future Technology

One of the challenges in future technology is to find effective, efficient, economical means to hydrolyze the cellulose and ferment the glucose produced to ethanol. Presently there are 2 basic options: 1). the use of concentrated strong acids, and 2). the use of cellulase enzymes. Both methods have advantages and disadvantages. Strong acids place severe chemical metallurgical requirements on the hydrolyzer and require some means of acid recovery and recycling. Enzymes are expensive, slow and not presently available in sufficient quantities for biomass to ethanol plants. Both of these methods are receiving intense scrutiny by university and government laboratories. These developments should be monitored carefully since significant increases in ethanol production per ton of biomass can occur if the cellulose can be cost effectively hydrolyzed.

Full Scale Plants - The full scale plants are beyond the scope of this plan in terms of detailed planning. The purpose of Phase II is to provide the engineering, economic and logistical information upon which full-scale biomass plants can be designed, financed, constructed and operated.

Operations

Near Term - Mr. James Stricker will assume the principal operational management to organize the legal entity, solicit cooperators and support and develop the structure for Phase I. The Mined Lands Center and the Institute of Phosphate Research may be important participants in the early part of the effort. As funds become available, Mr. Stricker will build the support staff necessary to plan and conduct Phase I. Mr. Stricker will also provide leadership in organizing

the Phase II structure and recruitment of the initial staff. This near term operation may require 12 to 18 months to plan and another 12 months to conduct.

Long term. - Long term operations is more difficult to describe at this time. The plan is to secure funding to recruit a small staff whose main responsibility will be to develop the legal and business structure for the Phase II Demonstration Plant and to secure the funding, planning, construction and operation of the plant. The nucleus of the long term management and operational team may overlap with Phase I.

Financial Information

Since UF/NERL Biomass to Ethanol, Inc. is only a conceptual entity, very little real financial information can be given. We have attempted to make very preliminary estimates of values. Many of the assets are embodied in information collected by the Mined Lands Center and by the Participants in this project. In normal accounting procedures these items would be expensed and would not appear as an asset; however, the information of the agronomic utility of the clay settling ponds for biomass production is the basis for the interest in this biomass to ethanol project. If this effort succeeds much of the impetus will be attributed to this information and data.

Assets:

1. Incorporation of UF/NERL Biomass to Ethanol, Inc.
2. Cash, Grants, Contracts,
3. Equipment, Leases
4. Data and Technology

Liabilities

The Liabilities will be the costs of planning, and carrying out Phase I and Phase II. Phase I will be a pure expense with no anticipated revenue beyond the sale of ethanol produced during the 30 day trial. This income may have to be used as an inducement to the ethanol plant cooperator, to interrupt the normal operations of the plant and any reduction in production or increase in operational costs caused by this feasibility study.

Phase II will generate income and according to the Pro Forma will show \$1 million of net income and \$1.8 Million cash to the equity holders for a net cash return to equity of 35%.

1. Phase I, Feasibility demonstration

(See Phase I budget to be developed as grants, cash and "in kind" donations can be determined.)

2. Phase II, Demonstration plant

Capital cost for 5 million gallon per year estimated to be \$13 million dollars based on an estimated cost of \$2.5 of capital per gallon per year capacity for the corn and sugarcane juice portion and \$3.00 per gallon per year for the hemicellulose from biomass portion.

3. Other Costs

Start up cost to develop Phase I and incorporate legal entity.
\$50,000

Total Development Costs

Phase I \$50,000 Plus other to be determined costs
Phase II \$13,000,000 preliminary first estimate.

Environmental and Regulatory Considerations

All intergeneric microorganisms require a Pre-Manufacturing Notification (PMN) be made to the USEPA prior to first manufacturing and that a notice Of Commencement of Operation be made after the initial PMN. The 30 day trial may not require a PMN and new regulations are being codified which may reduce the notifications. The bacteria are not plant or animal pests, and the use is for ethanol fuel and not for human use, so permits should not be difficult to obtain. So far the EPA has acted favorably on all PMN's which they have received. If the initial PMN were submitted in conjunction with this demonstration the EPA is expected to complete their review within 90 days.

The use of these bacteria for ethanol production would not require a specialized permit in Florida, but the plant would have to meet all state and local requirements regarding the containment fluids in tanks and for all other air, water and waste permits including hazardous materials.

Air and water permits should be obtained as a part of the Engineering Design contract.

Site Plan must be developed and approved locally as a part of the Engineering Design package.

Water Issues: Ethanol plants require significant amounts of water for mashing corn and for hydrolysis. It may be necessary to concentrate the cane juice prior to fermentation as well as the hydrolysis syrup. The water removed during concentration would be of good quality and could be recycled. Since there may be an excess of biomass residue, it may be important to use the extra energy to recycle as much of the water as possible and minimize the waste stream. The DDGS will be either dried or the moisture content will be low. The waste streams from the sugarcane juice fermentation will be mostly spent yeast, some of which will be used as nutrients in the bacterial fermentation of the hemicellulose sugars. The bacteria will produce very little biomass about 2 gram per liter of fermentation syrup. Waste water recycling will make permitting easier and reduce expenditures for waste water treatment.

Other wastes: Following the acid hydrolysis of the hemicellulose, the sulfuric acid is neutralized with hydrated lime producing gypsum. This material would not contain the level of Radium²²⁶ found in gypsum created by the production of phosphate fertilizer. Gypsum from a biomass plant could be used as a source of sulfur and calcium for agricultural crops.

Special Issue: Phosphate ore contains small amounts of radioactive uranium in the crystal structure of calcium apatite. Radium 226 is daughter product that is present in the clay in the settling ponds. It is estimated that ash produced by combustion of plants grown on these clays will contain 3 picocuries per gram. This information is contained in the report by Mr. W.V. McConnell. The Florida Department of Health and Rehabilitative Service indicated by letter that

if the anticipated levels of radium 226 are less than 5 picocuries per gram of ash, disposal by returning to the land should not create a radiological health hazard. Air emissions from the proposed project which entailed combining the residual biomass in existing fuel loads, urban wood wastes and biomass and scrap tires would not, at this time be subject to a federal radionuclide emissions standard.

Key Personnel and Management

Key personnel:

Mr. James A. Stricker - Extension Agent-Agriculture/Natural Resources, Director
Mined Lands Agricultural Research/Demonstration Project

B.S. University of Missouri - Columbia

M.S. University of Missouri - Columbia

* Gamma Sigma Delta

* USDA Distinguished Service Award, 1991

* Who's Who in the South and Southwest

* Who's Who in American Education

Mr. Stricker has been with the University of Florida/Polk County Extension Service since 1979. He gave leadership to the establishment of the Polk County Mined Lands Agricultural Research/Demonstration Project in 1985. The project has received grants totalling more than \$3.5 million and is an interdisciplinary research/education program aimed at finding and implementing productive uses for reclaimed phosphate land.

He served as County Extension Director from 1981 through 1990. During the period when he was Extension Director he administered the planning and construction of three buildings for the Polk County Agricultural Center. The total value of the construction program was \$1.75 million. Most of the building funds came from state grants.

Before coming to Polk County Florida, Mr. Stricker was an Extension Agent with the University of Missouri. He also served as Farm Manager, Research Farm Superintendent, and Research Associate, all with the University of Missouri Agricultural Experiment Station.

Mr. Stricker has published a number of papers in scientific journals and written numerous extension articles for local audiences.

Other key personnel:

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David L. Hall, President
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Economic Devel. Spec.,
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Mr. Stephen C. Reiser, C.E.O.
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William P. "Paddy" Rice
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Winter Park, FL 32790

Further Development Work Leading to Commercial System

21 Land and Plant Requirements

Demonstration Project

The first step in scaling up to a commercial system will be a joint project with an existing ethanol facility. Additional equipment to hydrolyze the hemicellulose in sugarcane presscake will be installed. About 240 to 280 acres of sugarcane will be needed to supply a 5,000,000 gal per year ethanol plant for about 30 days.

Pilot Plant

A 5,000,000 gal per year pilot plant capable of converting both sugars/starches and hemicellulose to ethanol is recommended. The plant will operate for 100 days each year on sugarcane with both sugars and hemicellulose being converted. The other 230 days per year the plant will be operated with elephantgrass and corn or waste materials. From 800 to 1,000 acres of sugarcane will be needed along with 1,000 to 1,200 acres of elephantgrass. Corn will be purchased on the market. Total land needed will be in the range of 1,800 to 2,200 acres.

Conceptualized Commercial Plant

The conceptualized commercial plant will be capable of producing 23,600,000 gal. of ethanol per year. During sugarcane harvest season, from November through February, the plant will be operated on sugarcane presscake and juice. About 4,500 acres of sugarcane will be needed to operate the plant for 100 days. For the additional 230 days of operation, the plant will use elephantgrass, leucaena, and *Eucalyptus*. A total of 128,000 dry tons of will be needed each year. If the mix of woody and herbaceous crops recommended by Rahmani and others in section 6 of this report is used, 51 % would come from *Eucalyptus*, 35% from elephantgrass and 14% from leucaena. *Eucalyptus* is harvested every 3 to 5 years while elephantgrass and leucaena may be harvested annually. Based on estimated annual yield for each crop, 6,500 acres of *Eucalyptus*, 2,500 acres of elephantgrass, and 1,200 acres of leucaena will be needed. This mix of biomass crops will extend the harvest season and reduce storage needs. Total crop acreage for the entire operation comes to 14,700 acres.

22. Additional Research Needed

In order for a biomass to energy system to be economically successful each individual component must be well thought out and designed to fit well with all other components in the system. The overall system must be very efficient to make it profitable. Each step has only a relatively small margin of error or the whole system becomes inefficient. Scale-up of the system will require that the entire system be carefully balanced. Additional research is needed to successfully scale-up a system from field plots and laboratory scale work to large scale commercial systems. A number of research needs have been identified.

Biomass Crop Production and Management

- * Continued work is needed in screening crop varieties for improved production. Also, work is needed to find tall grass varieties with perennial habit and high production which may be propagated to reduce establishment costs.
- * Work on fertilizer management and utilization of waste materials for fertilization of biomass materials to maintain high production levels and minimize environmental impacts.
- * Stand establishment of both vegetatively propagated and seed propagated crops needs attention. For example, a tall grass cultivar, called *erianthus*, has a higher biomass yield potential than elephantgrass but attempts to plant the crop have resulted in only half a stand. Plantings of *leucaena* on phosphatic clay have also resulted in less than desirable stands requiring interplanting in skips or plowing up and replanting.
- * *Leucaena* leaves are very high in protein and makes excellent animal feed. Work is needed on systems for multiple use of *leucaena* for both cattle feed and biomass.
- * There is a need to test more *Eucalyptus* genotypes on reclaimed phosphate land.
- * Present clone banks need to be expanded.
- * Low cost vegetative propagation methods for *Eucalyptus* needs to be developed.
- * Production of commercial quantities of *E. camaldulensis* and *E. amplifolia* is needed
- * Pilot scale plantings of the most promising species of crops are needed on all land types to confirm production levels and costs on a field scale rather than research plot scale.
- * Commercial harvest systems may have an impact on stand longevity. Trials are needed to test crop persistence under commercial type harvest.

Harvesting, Handling and Drying

- * Total crop production costs are sensitive to harvesting costs, which in turn are strongly affected by harvest efficiency. Harvest equipment proposed for our system has been used in Europe but no firm data was found on machine capacity, longevity, and maintenance needs under biomass crop harvest conditions. Field scale harvesting is needed under Florida conditions.
- * Operational performance of the entire harvest system needs to be examined to determine the appropriate balance of equipment for each unit and to evaluate overall system reliability.

- * Net energy yields from combustion of biomass fuels are largely determined by moisture content. Moisture level of biomass materials also impacted transportation costs. Field-drying of biomass is a low cost option, but may be associated with high dry matter losses. Field-scale trials are needed to test both equipment and assumptions on field-drying.
- * Drying systems need to be developed for left-over cellulose and lignin from bioengineered or NREL conversion systems, as well as fermentation process. One example is new technology in steam drying. This process may fit well with a power plant. Air drying systems under Florida conditions should also be examined.

Utilization of Waste Streams

- * Hydrolysis stillage characterization data should be obtained for pertinent feedstocks, hydrolysis methods, and fermentation schemes. These results should be considered during feedstock and process selection/optimization.
- * Waste streams should be characterized to determine possible use for animal feed or value as fertilizer.
- * As final selection of feedstock/process is approached, corresponding hydrolysis stillage treatability studies should be performed prior to preliminary process design and cost estimation.
- * As stillage treatability studies are performed, a simultaneous examination of effluent phytotoxicity on pertinent soils and cropping systems should allow methods for ameliorating such effects and to estimate the costs of these methods.
- * Conversion process design and implementation must consider the role of input chemicals and their fate to assure sustainability of the system. Both long-term use of Na (pH control), and the effects of heavy metals (as losses from corrosion of equipment) on the sustainability of the biomass cropping system should be addressed.

Conversion Processes

- * Scale-up of the bioengineered and NREL processes needs to take place in a "research oriented" study. Doing conversions on a large scale can reveal problem such as poor mixing in large batches, process reliability problems. Processes need to be verified at a large scale for system optimization.
- * Need to do a detailed material and energy balance study of system. Need to focus on ways to capture waste energy and reuse within the system. Also, focus on ways to completely use by-products. (ie drying and then burning for heat.)
- * Need to study ways to combine operations within the plant. For example, the ethanol drying process will be the same for all three potential conversion systems. There may be other similar processes that can be combined to reduce capital costs.

23. Pre-commercial pilot plant

The pre-commercial pilot plant is described in section 20 under the preliminary business plan.

24. Conceptualized Commercial System

Ashley Vincent and Evelyn Vincent²¹

Introduction

This commercial system is built around a 5,000,000 gal. per year capacity conventional ethanol plant, coupled with a lignocellulose conversion facility. Enough sugarcane would be grown to supply the 5,000,000 gal. per year capacity plant with feedstock for 330 days per year, with double pressing to extract the sugar containing juice. The associated lignocellulose conversion facility would have sufficient capacity to process the sugarcane presscake during the 100 day sugarcane harvest season. The remaining 230 days of operation, the lignocellulose plant would convert elephantgrass, leucaena or *Eucalyptus*. Total plant capacity would be 23,600,000 gal of ethanol per year with both juice and lignocellulose conversion.

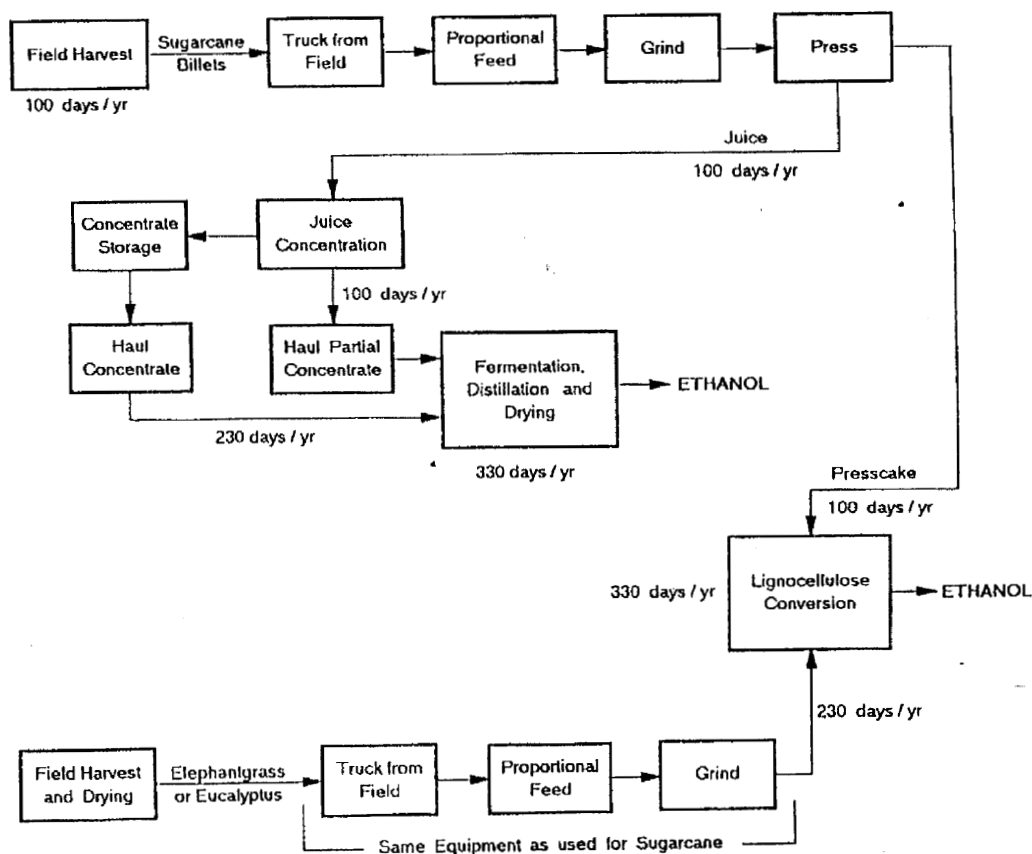


Figure 24-1. Two stage pressing of sugarcane with lignocellulose in presscake and other biomass materials converted to ethanol.

Pre-Processing Facility - Multiple Pressing

Figure 24-1 presents an overall flow diagram of a multiple pressing operation, including lignocellulose conversion of presscake and other feedstocks.

Presses will be installed in a pre-processing facility located as closely as possible to the largest production fields. Sugarcane will be harvested as billets and transferred from field wagons to trucks at the edge of each field.

Field Unit:

- 1 Harvester to cut sugarcane into billets
- 2 Tractors each pulling 2 field wagons

Billets will be transferred to over-the-road trucks from an earth-mound raised dump at the edge of the field.

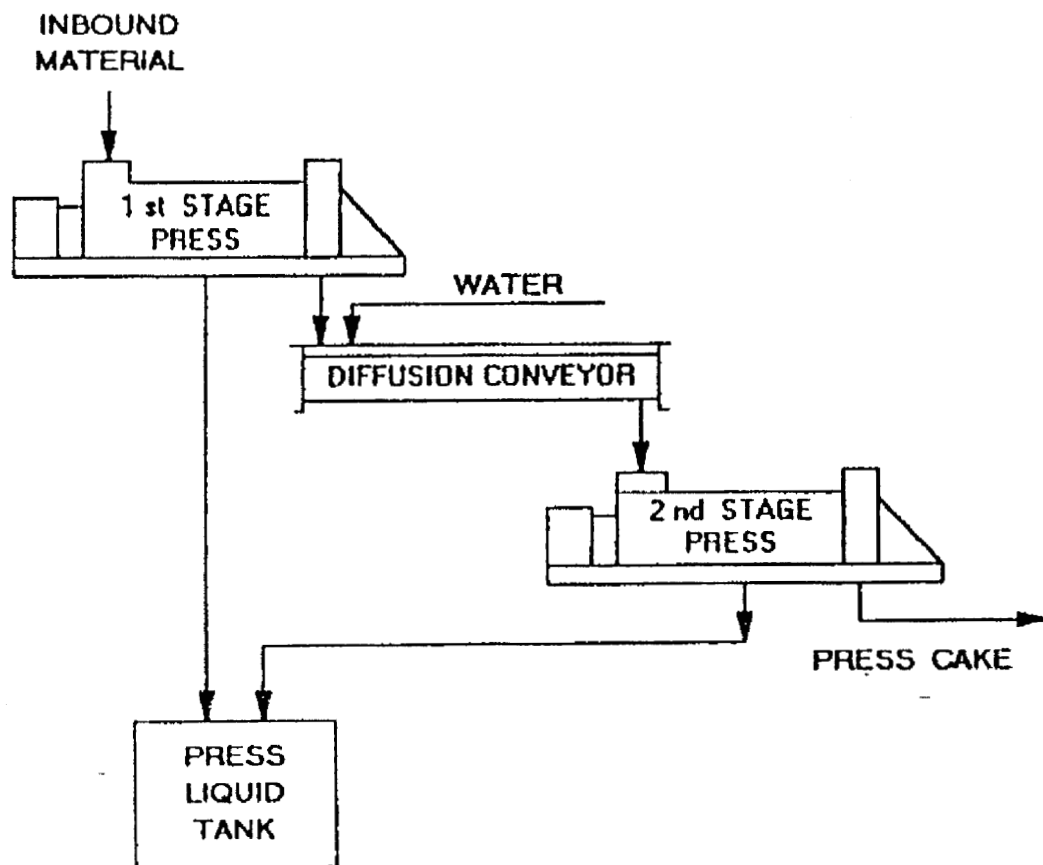


Figure 24-2. Two-stage pressing using two presses.

Billets will be trucked to the pre-processing facility and dumped on a slab area having proportional dragline feeders to supply grinders and presses in the plant. Front-end loaders will move the billets from the truck dump piles into the proportional feeders.

Sugarcane billets will be ground and pressed in two working shifts (16 hours per day). Assuming a 100-day harvest season, the presses will operate 1,600 productive hours per year.

Double Pressing:

To supply juice to produce 5,000,000 gallons of ethanol per year will require 360,000 green tons per year of sugarcane using double pressing with tandem stages (figure 24-2). At 80 tons per acre, 4,500 acres will be harvested annually. Process water will be added ahead of the second stage. This double pressing will separate about 82% of the available sugar into juice, producing 4,800 gallons of juice per hour from each press tandem.

Table 24-1. Estimated Cost of Producing Ethanol from Sugarcane Grown on Phosphatic Clay Soil - Double Pressing

Operation Hours per year	-----Dollars-----		-----Dollars per Gallon of Ethanol-----		
	Per hour	Per dry ton	Juice only	Juice & fresh presscake	Juice & ensiled presscake
Establishing, Maintaining, and Harvesting-6 Units (1100 hrs)	2,288.00	28.47	0.503	0.225	0.252
Trucking from Field - 18 Trucks (1100 hrs)	897.00	11.16	0.197	0.088	0.099
Proportional Feeder - 6 Units (1600 hrs)	260.00	4.71	0.083	0.037	0.042
Grinding - 3 Units (1600 hrs)	91.70	1.66	0.029	0.013	0.015
Pressing -15 Units (1600 hrs)	437.00	7.91	0.140	0.062	0.070
Juice Concentration (24° Brix) (2400 hrs)	36.90	1.00	0.018	0.008	0.009
Juice Hauling (24° Brix) (2400 hrs) 3 Tankers	59.10	1.60	0.028	0.013	0.014
Juice Concentration (70° Brix) (2400 hrs)	147.60	4.01	0.071	0.032	0.035
Concentrate Storage (70° Brix) (5520 hrs)	40.80	2.55	0.045	0.020	0.023
Concentrate Hauling (70° Brix) (5520 hrs) 1 Tanker	20.70	1.29	0.023	0.010	0.011
Juice to Ethanol (7920 hrs)	322.00	28.85	0.510	0.228	0.255
Presscake to Ethanol (2400 hrs)	1705.00	46.29	----	0.365	0.330
Total Costs	6,305.80	139.50	1.65	1.10	1.16

Each first stage press will process 25 green tons per hour or 40,000 green tons per year. Nine presses will be required for this first stage.

The second stage presses will need to process the presscake (161,000 tons per year) from the first stage plus 66,000 tons of water added. This water will be recirculated from juice evaporator condensate. The inbound feed to the second stage presses will be 227,000 tons per year. This will require six presses for the second stage. The two-stage system will produce a total output of 68,000,000 gallons of juice per year.

During the 100-day harvest season 30 percent of the juice will be pasteurized and concentrated in an evaporator to 24 degrees Brix. This evaporator, operating on biomass fuel, will significantly reduce hauling costs, allow short-term storage, and improve efficiency of the ethanol conversion. The remaining 70 percent of the juice, concentrated to 70 degree Brix, will be stored to allow operation of the ethanol plant for the remainder of the year.

Plant Operation

During the 100-day harvest season fresh presscake will be processed in lignocellulose conversion equipment. This conversion process will be sized to handle all of the presscake produced each day during the sugarcane harvest season and will then be available to operate on stored hay or woody biomass after the sugarcane harvest is completed. The sugarcane presscake can provide an additional 6,200,000 gallons of ethanol per year (90% yield). With the lignocellulose facility available during the remaining 230 days of the year for conversion of other biomass feedstocks, the total annual production of ethanol could be increased to 23,600,000 gallons per year.

Table 24-1 shows cost estimates reflecting the sugarcane operation showing a maximum production of 11,200,000 gallons of ethanol per year from 4,500 acres of sugarcane.

Approximately 4,500 acres of sugarcane yielding 80 green tons per acre will be needed to supply sugar for the 5,000,000 gal per year plant. This is equivalent to a total of 360,000 green tons or 88,400 dry tons per year.

Assuming a 68% ethanol yield from biomass other than sugarcane, about 10,200 acres will be needed to operate the lignocellulose plant for the remaining 230 days of the year (table 24-2). About 512,000 green tons or 128,000 dry tons will be needed each year. Ethanol yield from biomass other than sugarcane would be 12,400,000 gal. per year. The entire operation would produce 23,600,000 gal of ethanol per year.

Table 24-2. Estimated Cost of Producing Ethanol from Elephantgrass, *Eucalyptus* or *Leucaena*

Operation Hours per year	-----Dollars-----		
	Per hr.	per dry ton	Gal. of Ethanol
Establishing, Maintaining, and Harvesting	----	27.21	0.281
Trucking from Field (1800 hours)	496.70	7.14	0.074
Proportional Feeder (3680 hours)	66.60	1.91	0.020
Grinding (3680 hours)	30.50	0.88	0.009
Biomass to Ethanol (5520 hours)	1,736.00	74.87	0.773
Total Costs	2,329.80	112.01	1.16

Lignin residues from the lignocellulose conversion process will be used to fuel evaporators used to condense sugarcane juice. Excess lignin can be used in a direct combustion process to generate electricity.

Appendix A

Directory of Project Participants

A.1 Project Participants

Table A-1. Directory of Project Participants
NREL Project: Economic Development through Biomass Systems
Integration in Central Florida

Name	Organization	Address	Phone/FAX
Dr. Wayne H. Smith	University of Florida Center for Biomass Programs	P.O. Box 110940 Gainesville, FL 32611	904/392-1511 904/392-9033
Mr. James Stricker	Polk County Extension Service	1702 Hwy 17-98 South Bartow, FL 33830	813/533-0765 813/534-0001
Dr. Wayne Mishoe	University of Florida Agricultural Engineering Dept.	P.O. Box 110570 Gainesville, FL 32611	904/392-2914 904/392-4092
Dr. Don Rockwood	University of Florida School of Forestry	P.O. Box 110420 Gainesville, FL 32611	904/846-0897 904/392-1707
Dr. Clyde F. Kiker	University of Florida Food and Resource Economics	P.O. Box 110240 Gainesville, FL 32611	904/392-2396 904/392-3646
Dr. Alan Hodges	University of Florida Food and Resource Economics	P.O. Box 110240 Gainesville, FL 32611	904/392-5072 904/392-8634
Dr. Mohammad Rahmani	University of Florida Food and Resource Economics	P.O. BOX 11240 Gainesville, FL 32611	904/392-9896 904/392-2395
Dr. Gordon M. Prine	University of Florida Agronomy Department	P.O. Box 110500 Gainesville, FL 32611	904/392-1811 904/392-1840
Dr. Ann Wilkie	University of Florida Soil & Water Science Dept.	P.O. Box 110960 Gainesville, FL 32611	904/392-8699 904/392-7008
Dr. John Gerber		1126 NW 57th Street Gainesville, FL 32605	904/332-8225
Dr. Kareem Asghari	University of Florida Microbiology and Cell Science	P.O. Box 110700 Gainesville, FL 32611	904/392-1906 904/392-5922
Mr. Richard Schroeder	Kenetech Recovery Inc.	P.O. Box 147050-347 Gainesville, FL 32614	904/377-8282 904/378-6804
Mr. W. V. McConnell		1023 Luis Road Tallahassee, FL 32304	904/576-7774 904/576-7774
Mr. Phil Tuohy	Ridge Generating Station	3131 K-Ville Avenue Auburndale, FL 33823	813/665-2255 813/665-0400
Mr. Nathan Duncan	Bartow Ethanol Inc.	P.O. Box 1966 Bartow, FL 33831	813/533-2498 813/533-2498
Dr. Ashley Vincent Mrs. Evelyn Vincent	Savant-Vincent, Inc.	166 Baltic Circle Tampa, FL 33606	813/254-0036 813/254-9936
Mr. Macauley Whiting, Jr.	Decker Energy International, Inc.	400 N. New York Ave. Suite 101 Winter Park, FL 32789	407/628-8900 407/628-8535

Appendix B

Land Availability and Value

B.1 Land Availability and Value

LAND AVAILABILITY AND VALUE

CENTRAL FLORIDA RECLAIMED PHOSPHATE LANDS

(TASK 2A)

NREL RENEWABLE ENERGY PROJECT

REVISED NOVEMBER, 1994

NREL RENEWABLE ENERGY PROJECT

LAND AVAILABILITY AND VALUE

EXECUTIVE SUMMARY

Certain lands, because of their unique physical, locational or ownership characteristics, are peculiarly suited for renewable energy production. These "niche lands" include reclaimed mined land in Polk and Hillsborough Counties in central Florida. About 82,000 acres of these lands are, nominally, on the market, or will appear on the market in the near future. Another 34,000 acres will come on line in the next 10 years. Of this 116,000 acres, we estimate, conservatively, that 73,000 acres will be available for energy biomass production with 37,000 acres in "clay settling areas": lands that are highly productive and suited only for agricultural use. The remaining 36,000 available acres will consist of "mined out lands" which are less productive. The market value of lands primarily suited for agricultural use is low (\$1,000 - \$2,000 per acre) and the rental values very modest (\$15 - \$20 per acre per year). The usable land occurs in large tracts and is controlled by a fewer than 15 owners.

With the planned construction of 3 large electrical generating facilities having a combined capacity of over 5,000 Mw, plus several smaller generating and co-generating plants, southwestern Polk County is emerging as the "energy capital" of Florida. This situation creates the opportunity for developing fossil/renewable fuel energy complexes offering benefits to both host (fossil fueled) and satellite (bio-fueled) components. Optimized fuel-sheds serving these development centers would allow an average fuel haul of less than 10 miles.

Should this project proceed to the next phase, a much more opportunity-focused land examination, along with tract-specific negotiations will be needed.

BACKGROUND

This report deals with the availability and value of lands suitable for renewable energy farming in Polk and Hillsborough Counties as shown in Map I, an area of about 910 square miles or 600,000 acres. Agriculture in the area is based on livestock and citrus. A large area (210,000 acres) is in unimproved pasture, much of it rented on an annual basis at low rates. In the entire county, only 1,100 acres is in row crops and the freeze of 1989 required extensive replanting of citrus groves, especially in the northern portion of the county. Owners have replanted most of the frost-affected groves, either in citrus or pine.

This report focuses on reclaimed mined lands because here is where both the problem and opportunity lies. While energy-crop farming might compete economically with cattle production on the 210,000 acres of unimproved pasture, these lands, now in productive though low use, are located in the northern and eastern part of the county.

The un-used reclaimed mined lands, the region's principal economic problem and potentially most productive lands, are located in the southern and western portion of the county. While non-mined lands could be a factor in individual cases, they are not considered a significant factor in this macro-study.

Phosphate mining in Polk County has been a major industry in Central Florida for over 100 years. Early mining was centered in northern and central Polk county and is now moving into northern Hardee and southeastern Hillsborough Counties. Some 14 companies have been recently active in mining in Central Florida. As a result of consolidations and other factors, membership in the Florida Phosphate Council (the industry's trade organization) has declined from 12 in 1992 to 7 in 1994. Through June 30, 1993, a total of some 180,000 acres has been disturbed and mining is presently proceeding at the rate of about 5,000 acres annually. Total land reclaimed and under contract for reclamation through that date is 82,000 acres.

Economically recoverable phosphate deposits could be exhausted early in the next century, possibly by the year 2020. Of more significance to the proposed project is the projected near-future closure of several major mines containing substantial acreage. Table 1 lists currently active mines with their projected shut-down dates.

For purposes of reclamation funding, mined lands in Florida are divided into "old lands" (mined before 1975) and "mandatory" lands. The law prior to 1975 did not require reclamation as does the new law under which mined lands must be restored to established standards by the mining company. Funding for reclaiming eligible "old" lands may be furnished by the State from a trust fund financed by a phosphate severance tax. One June 30, 1993 the fund contained \$112,000,000 of which \$69 million was un-allocated. New revenues amount to \$18 million per year.

To oversimplify, reclaimed mined land falls into 3 categories. Mined out areas (MOAs) are a mixture of the original soils which have been removed from over the phosphate ore and are pushed back into the mined areas after the mining is completed. These are widely variable but are generally infertile. Earlier mining operations resulted in a land form consisting of a mixture of usable land and lakes (valuable for recreation and residential development). More recent operations have aimed at a land form approximating pre-mined condition (valuable for renewable resource and commodity production). Under these preferred practices, water areas are minimized by lowering the elevation of the contoured overburden, thus spreading the available soil over a greater area.

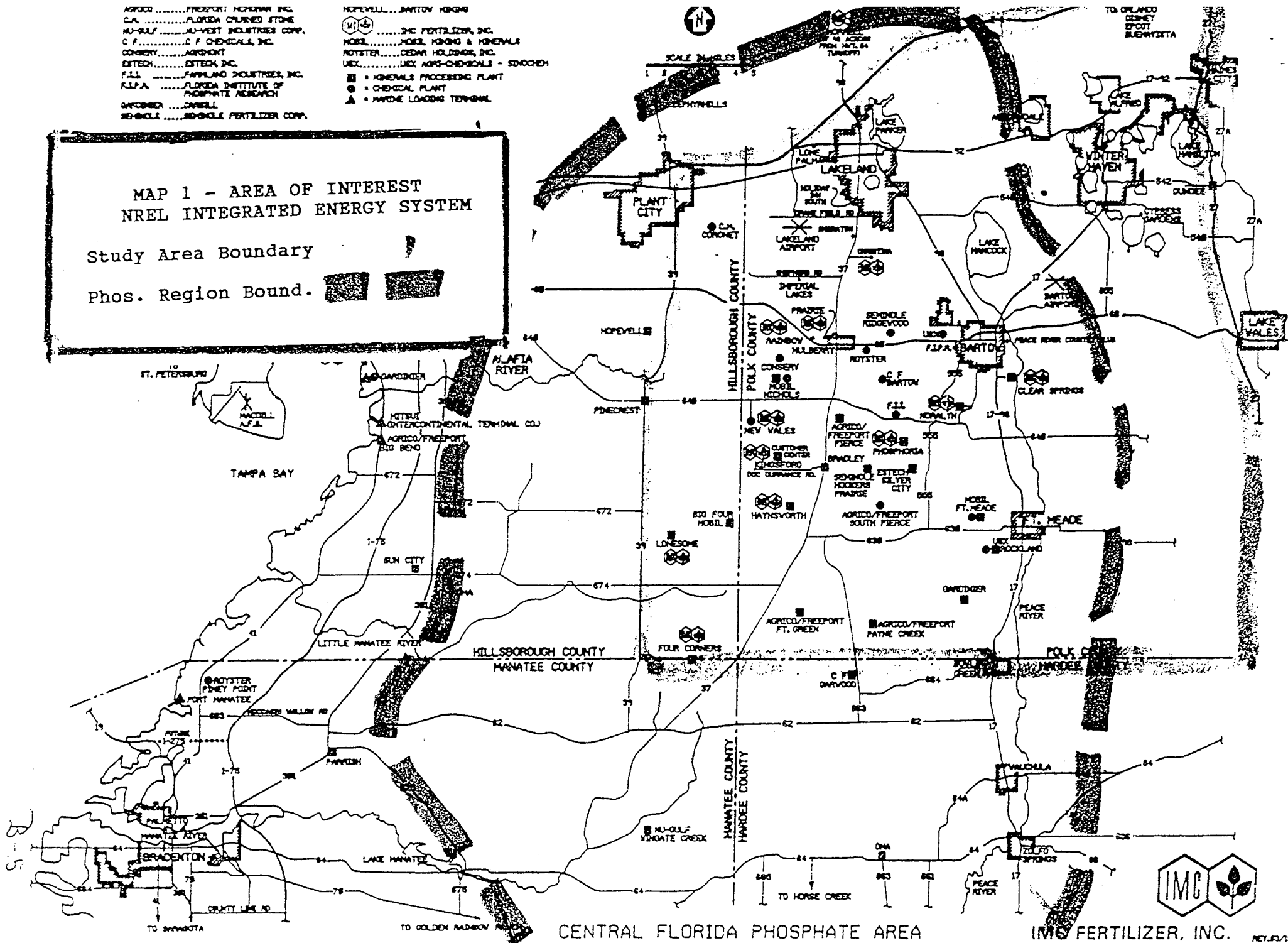
Clay settling areas (CSAs) typically are impoundments into which are pumped the clay slurry which remains after the phosphate has been removed from the ore. After dewatering (an expensive process requiring 18 months or more) these soils are ready for agricultural use and are highly productive.

AGRI-CO FORT LINDSEY, INC.
 CA FLORIDA CRUSHED STONE
 MO-BULF MO-VEST INDUSTRIES CORP.
 C.F. C.F. CHEMICALS, INC.
 CONSERV CONSERV
 ESTECH ESTECH, INC.
 FILL FAYLAND INDUSTRIES, INC.
 ALP-A FLORIDA INSTITUTE OF
 PHOSPHATE RESEARCH
 GARDNER GARDNER
 HEM-BOL HEM-BOL FERTILIZER CORP.

HOPEVELL BARTON KIRK
 IMC IMC FERTILIZER, INC.
 MOSEL MOSEL MINING & MINERALS
 ROYSTER CEDAR HOLDINGS, INC.
 UEL UEL AGRO-CHEMICALS - SMOCKEN
 • MINERALS PROCESSING PLANT
 • CHEMICAL PLANT
 ▲ HARBOUR LOADING TERMINAL

MAP 1 - AREA OF INTEREST NREL INTEGRATED ENERGY SYSTEM

Study Area Boundary
 Phos. Region Bound.



CENTRAL FLORIDA PHOSPHATE AREA

IMC FERTILIZER, INC.

NET-10/12

COMPANY & MINE

ACTUAL OR ANTICIPATED MINE OUT DATE
MONTH/YEAR

CAR - CARGILL FERTILIZER, INC.	
FM - FT MEADE	3/2006
BL - BONNY LAKE	2/84
HP - HOOKERS PRAIRIE	2007
CFM - CF MINING	
HC1 - HARDEE COMPLEX I	6/93 (7 yrs mining remaining-to sell
HC2 - HARDEE COMPLEX II	6/2023 options)
EST - ESTECH	
SC - SILVER CITY	1/92
W - WATSON	3/89
IMC - AGRICO	
FG - FT. GREEN	2008
PC - PAYNE CREEK	2001
PD - PEBBLEDALF	1998
CS - CLEAR SPRINGS	1998
FC - FOUR CORNERS/LONESOME	2015
HW - HOPEWELL	2010
KC - KINGSFORD COMPLEX	2001
NP - NORALYN/PHOSPHORIA	1998
NW - NEW WALES	1995
MCC - MOBIL CHEMICAL COMPANY	
FM - FT MEADE	5/90
N - NICHOLS	temporarily shutdown no projected start up date but 8-9 yrs mining remaining
SF - SOUTH FT MEADE	1/2017
BF - BIG FOUR	10/95
NGI - NU-GULF INDUSTRIES, INC	
WC - WINGATE CREEK	temporarily shutdown no projected start up date
OCC - OCCIDENTAL CHEMICAL COMPANY	
SC - SWIFT CREEK	2010
SR - SUWANNEE RIVER	2012
TWC - THE WILLIAMS COMPANY	
SC - SADDLE CREEK	12/86
USS - U.S. AGRI-CHEMICALS	
R - ROCKLAND	8/94

From: BHR
Updated 6-29-94

TABLE 1
Mine Closure Dates

Sand removed from ore during processing is pumped back into mine pits and covered with overburden. In some operations the sand is pumped into or over CSAs. Areas of sand disposal are called sand tailing areas (STAs). STAs are generally infertile and, for purposes of this study, are classed with MOAs.

The application of these reclamation techniques has varied over the years and by mines. A conceptual waste disposal plan for a "representative" mine is shown in Map 2.

Competition of other uses will determine the degree of availability, and value, of reclaimed lands for agriculture. MOAs are suitable for residential, commercial or recreational development and, in the vicinity of cities or along highways will be more valuable for these purposes. CSAs, on the other hand, are both highly productive and unsuited for these competing uses. For these reasons, this study focuses on the clay settling areas as being most appropriate for bio-energy farming with the land intensively managed for annual or biannual crops of warm-weather grasses, energy cane or leucaena. MOAs appear to be best suited for tree crops managed on a multi-year rotation.

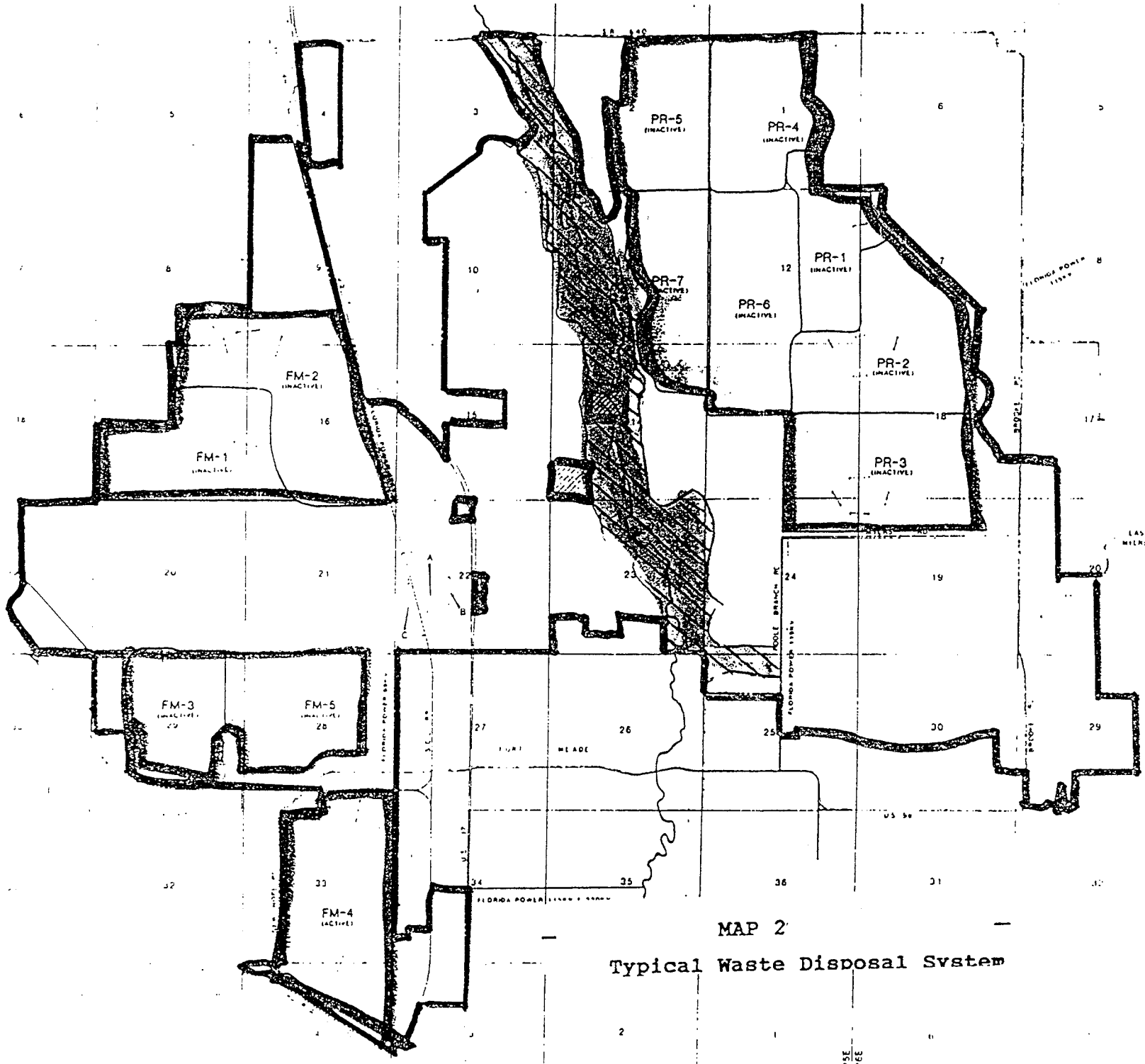
Phosphate mining, and attendant land reclamation, is a huge, complex and dynamic industry. Study resources did not allow an in-depth examination of the land resource. The depth of analysis is considered adequate for the present study. A much more focused investigation of individual opportunities and local situations will be needed, should the project advance to the next phase.

METHODOLOGY

To elicit information on availability and price, I sent written inquiries to:

- nine past or present members of the Florida Phosphate Council and to 5 other central Florida phosphate operators.
- thirteen current applicants for funding under Reclaimed Mine Area Act, not included in above.
- thirty nine selected Polk County landowners holding title to 2,000 or more acres.
- a 5% sample (57) of all Polk County "greenbelt" landowners owning more than 40 acres.
- Trustees of the Internal Improvement Fund, Central Florida Water Management District, Tampa Electric Company, Florida Power Company, City of Winter Haven Water & Sewer Dept, Lykes Corporation, Battle Ridge Corp.

8-8



- LEGEND**
- ☐ OUT PARCELS (NOT OWNED BY A)
 - SETTLING AREAS
 - A BENEFICIATION PLANT
 - B OFFICE
 - C MAINTENANCE & WAREHOUSE
 - POWER TRANSMISSION
 - RIVERWIDE CORRIDOR
 - MINE BO

MAP 2
Typical Waste Disposal System

MAP III.3.
Permanent structures &
clay waste storage sil
NE WISCONSIN

I also interviewed:

Staff of the Florida DEP, Bureau of Mine Reclamation (BMR). BMR staff persons were extremely helpful and are the principal source of the maps, information and statistical data in this report.

Bob Shirley, Reclamation Engineer, Brewster Corp. (Cytex Energy)
Bill Hawkins, Reclamation Engineer, Mobil Mining & Mineral Corp.
Paddy Rice, Land Manager, IMC-Agrico
Connally Barnett, Reclamation Engineer, Estech
Wayne Brobeck, Land Manager, U.S. Agri.Chem.
Geo. Shahadi, Mgr. Acq. & Real Estate, Williams Acq. & Holding Co.
Wayne Sampson, CF Mining
Tom Meyers, Cargill Fertilizer, Inc.
Jim Allen, Battle Ridge Corp.
Jim Stricker, Polk County Extension Agent
Ed. Coleman, Polk County Property Appraiser and Brooks Register, staff.
W. David Carrier III, Bromwell & Carrier, Inc.
Al Pisaneschi, Polk County Land Appraiser and broker.
John Hunt, Polk County, Land Appraiser and Broker
Brian W. Sodd, Central Florida Regional Planning Council
Brenda Taylor, Central Florida Development Council.
Buck Owen, Power Plant Siting Coordinator, Florida DEP

FINDINGS

The 5 responses from generalized written inquiries were inadequate to establish availability or value of non-mined lands. The team's original intention was to include these lands in the bio-fuel producing land base. While they may eventually contribute to bio-fuel production, they are, in my judgement, a non-significant factor in establishing the feasibility or scope of an integrated energy system in Polk County. The responses did indicate some interest on the part of landowners in growing crops for sale to a local assured market. Again, I judge this as a non-significant factor in the present study. Should the study proceed to the next phase in which the feasibility of specific project/sites are investigated, these options should be considered.

LAND AVAILABILITY...

Reclamation standards are governed by regulation and have a common basis throughout the industry. Post-reclamation management is another matter. Discussion with industry representatives revealed a interesting array of philosophies and policies concerning both short-term management of, and long term goals for, reclaimed lands. Short-term leases are the standard. I am led to believe that, in some cases, lease policies might be negotiable under special circumstances. However, the main interest of this conservative and highly individualistic industry is mining, not land and resource

management. Negotiations for long term leases will be difficult and favorable results problematic. Land purchase may be the only feasible option.

The near-future mine closings mentioned earlier (Table 1) will have a major effect on lease and sale policy as the involved companies move out of their current short-term holding pattern and into a final land disposition mode. Under these circumstances the purchase, rather than lease, of lands may be the more achievable alternative.

Availability unknowns include 3,500 acres of CSA, along with options for additional CSAs that may be reclaimed, that have been recently leased by an alternative energy company. How these lands may fit into an NREL sponsored program is unclear.

In the potential resource base I have included lands that are reclaimed, have BMR approval for reclamation or are covered by "intent to reclaim" notice, . An unknown fraction of this total will be unavailable for energy-related use due to environmental coordination needs, or because land location (for MOAs) make the land more suited for non-agricultural development. On the basis of discussion with BMR personnel and study of the *Regional Conceptual Reclamation Plan for the Southern Phosphate District* (Cates, 1992), I speculate that this fraction amounts to 15% for CSAs and 50% for MOAs.

The Florida DEP Bureau of Mine Reclamation synthesized existing mined-lands graphics into a location/status map (Exhibit I). This BMR map and related statistical data provided the basis for a simplified, consolidated mine location "work map" (Exhibit II). These mine locations are linked to the area estimates given in Tables 2 and 3 below. The BMR sorted and made available statistical data on reclaimed and other status lands. I edited and consolidated these data into Tables 2 and 3.

STATUS - ALL MINED PHOSPHATE LANDS
POLK & HILLSBOROUGH COUNTIES, FLORIDA

COMPANY MINE	MANDATORY			NON-MANDATORY			ALL LANDS		
	CSA	MOA	TOT	CSA	MOA	TOT	CSA	MOA	TOT
<hr/>									
LEWSTER									
KINGS-4CNRS	3213	4306	7519	5986	6254	12240	9199	10560	19759
CGILL									
FT. MEAD	2288	4355	6643	1302	0	1302	3590	4355	7945
HOOKERS PR.	1809	3101	4910	0	615	615	1809	3716	5525
BONNIE LAKE*	0	1956	1956	4543	1232	5775	4543	3188	7731
CF MINING									
HARDEE	0	1456	1456	0	0	0	0	1456	1456
ESTECH									
SILVER CITY*	829	1133	1962	1528	517	2045	2357	1650	4007
WATSON*	264	2589	2853	1428	471	1899	1692	3060	4752
IMC-AGRICO									
CLEAR SPRGS.	2184	2216	4400	1620	1044	2664	3804	3260	7064
FT. GREENE	4845	9080	13925	623	0	623	5468	9080	14548
4 CRNS-LONESM	4585	243	4828	1774	744	2518	6359	987	7346
HOPEWELL	1040	0	1040	2455	2266	4721	3495	2266	5761
KINGS-HAYS	5665	4185	9850	6238	1608	7846	11903	5793	17696
NEW WALES	0	1052	1052	0	0	0	0	1052	1052
RYLN-PHOSPHORIA	2991	4800	7791	6247	1633	7880	9238	6433	15671
AYNE CR.	1655	4621	6276	4631	6983	11614	6286	11604	17890
PEBBLEDALE	0	1002	1002	423	385	808	423	1387	1810
MCIL M&M									
IG FOUR	1620	1278	2898	0	0	0	1620	1278	2898
FT. MEADE*	2266	3313	5579	4475	612	5087	6741	3925	10666
NICHOLS	1445	1627	3072	1414	0	1414	2859	1627	4486
WILLIAM ET AL									
SADDLE CR.*	0	1532	1532	5986	6254	12240	5986	7786	13772
US AGRI CHEM									
ROCKLAND	1638	2841	4479	3035	691	3726	4673	3532	8205
TOTALS	38337	56686	95023	53708	31309	85017	92045	87995	180040

(1) APPROXIMATE AND PARTIAL, TRACTS COMBINED OR DELETED, TO BE USED
ONLY FOR DETERMINATION OF GROSS FEASIBILITY.

TABLE 2
STATUS OF ALL MINED PHOSPHATE LANDS

STATUS - RECLAIMED PHOSPHATE LANDS(1)
POLK & HILLSBOROUGH COUNTIES, FLORIDA

COMPANY MINE	MANDATORY (2)			NON-MAND. (3)			ALL RECLAIMED		
	CSA	MOA	TOT	CSA	MOA	TOT	CSA	MOA	TOT
<hr/>									
BREWSTER									
KINGS-4CNRS	1456	5136	6592	2528	6254	8782	3984	11390	15374
CARGILL									
FT. MEAD	0	3625	3625	1302	0	1302	1302	3625	4927
HOOKERS PR.	0	2306	2306	0	1463	1463	0	3769	3769
BONNIE LAKE*	0	1956	1956	4543	1047	5590	4543	3003	7546
CF MINING									
HARDEE	0	569	569	0	0	0	0	569	569
ESTECH									
SILVER CITY*	200	1048	1248	881	235	1116	1081	1283	2364
WATSON*	85	2768	2853	1303	315	1618	1388	3083	4471
IMC-AGRICO									
CLEAR SPRGS.	0	1634	1634	971	380	1351	971	2014	2985
FT. GREENE	1032	4473	5505	556	0	556	1588	4473	6061
4 CRNS-LONESM	0	1415	1415	320	1387	1707	320	2802	3122
HOPEWELL	0	151	151	821	721	1542	821	872	1693
KINGS-HAYS	0	4581	4581	5900	913	6813	5900	5494	11394
NEW WALES	0	140	140	0	0	0	0	140	140
NRYLN-PHOSPHO	669	4208	4877	6143	1379	7522	6812	5587	12399
PAYNE CR.	0	3614	3614	4081	4648	8729	4081	8262	12343
PEBBLEDALE	0	0	0	218	330	548	218	330	548
MOBIL M&M									
BIG FOUR	0	1209	1209	0	0	0	0	1209	1209
FT. MEADE*	0	3895	3895	4203	593	4796	4203	4488	8691
NICHOLS	0	953	953	1414	0	1414	1414	953	2367
WILLIAM ET AL									
SADDLE CR.*	0	1410	1410	2528	5029	7557	2528	6439	8967
US AGRI CHEM									
ROCKLAND	0	2035	2035	2742	691	3433	2742	2726	5468
TOTALS	3442	47126	50568	40454	25385	65839	43896	72511	116407

(1) APPROXIMATE AND PARTIAL, TRACTS COMBINED OR DELETED, TO BE USED ONLY FOR DETERMINATION OF GROSS FEASIBILITY.

(2) LANDS RECLAIMED THROUGH DEC. 31, 1993

(3) LANDS RECLAIMED, APPROVED OR APPLIED FOR THRU JUNE 30, 1993. INCLUDES 341K ACRES FOR WHICH "INTENT" NOTICE HAS BEEN FILED.

* MINED OUT

TABLE 3
STATUS - RECLAIMED PHOSPHATE LANDS

LAND VALUES...

I consolidated information gathered in interviews and from land appraisals and other documents made available to me (see exhibit III) into Table 4. Tract sales of any size almost always involve more than one land form. I found no transactions involving the sale of only reclaimed clay settling areas. The value of \$1,500 per acre for CSAs is highly speculative. Rental values for CSAs for energy crop production is based on a single 10 year lease for 3,500 acres plus additional options.

Information on sale and lease values for rough pasture MOAs is readily available. An IFAS study of Polk County pasture rentals (*Survey of Pasture Rental in Polk County - 1991*, J.A. Stricker, J.S. Brenneman and S.L. Sumner) showed the average per acre rental in the southwest sector of the county, an area primarily MOAs, to be \$7.54. This figure is consistent with rates quoted by company land managers, area land appraisers and brokers, but is below current rates for large tracts. In my judgement, annual pasture rental rates do not represent values for long-term leases for energy-crop production on large areas. Land managers are reluctant to set these values and the long-term lease values given in Table 4 reflects my best judgement.

I feel it probable that an actual acquisition or rental program at the scale envisioned in this project will result in an increase in these values. On the other hand, planned mine closings (Table 1) will result in greater land availability which will tend to depress prices. Values for individual tracts will, of course, vary with location, access and potential for other development.

Again, should this study evolve to an operational level, "hands-on" site-specific negotiation will be an imperative.

	<u>Market value</u>	<u>Rental value</u>
Clay settling areas	\$1,500	\$20
Mined out areas	\$1,275	\$15

Table 4. Land Values by productivity class.

A land value analysis appears in Exhibit III.

POSSIBLE APPLICATIONS OF INFORMATION

The next phase of this study will examine the specific opportunities identified in this initial scoping exercise. Here are some suggestions:

- The spatial distribution of available lands seems to result in natural groupings around existing or planned bio-fuel consumers. These development centers (shown on Exhibit II) and their fuel-sheds could serve as the basis for the second phase of this study.
- Perhaps the most important of these options involves the three very large electrical generating facilities which will be constructed in southwestern Polk county in the next few years. The initial capacity for these facilities totals 3,000 MW with planned expansion to over 5,000 MW. The construction of these fossil fuel based facilities in a large area of dedicated feedstock supply system (DFSS) suitable and unused land offers an opportunity for an integrated fossil/renewable fuel system. In such a system, one or more small (20-50 MW) satellite renewable systems (Independent Power Producers?) together with its adjacent DFSS could complement the host fossil system. By using the host's infrastructure (management, technical, transportation, operating) the satellite system could achieve substantial saving in installation and operating costs. Such a symbiotic arrangement would offer the a number of advantages (diversification, PR, mitigation of CO₂ emissions, earned SO_x emission credits) to the host utility. I strongly recommend that the planning team consider this as a preferred option.

Revised November, 1994

W.V. McConnell

Land Management Planner/Forester

EXHIBIT III LAND VALUE ANALYSIS

<u>ESTIMATE/ QUOTE</u>	<u>MINED OUT AREAS</u>		<u>CLAY SETTLING AREAS</u>	
	<u>VALUE</u>	<u>RENTAL</u>	<u>VALUE</u>	<u>RENTAL</u>
IFAS STUDY(1)	-	\$7.54	-	\$7.54
INDUSTRY .A	-	-	\$1500	-
INDUSTRY .B	-	5 - 7	-	10
INDUSTRY .C	-	5 - 15.50	-	(CROP) 55(2)
INDUSTRY .D	=	13.50	-	-
INDUSTRY .E	-	14 - 18	-	14 - 18
INDUSTRY .F	-	7.50 - 15	-	7.50 - 15
APPRAISER A \$1200		-	-	-
APPRAISER B 800/1200		-	-	-
APPRAISER C 1000		8 - 15	-	8 - 15
<u>TRANSACTION</u>				
A 1120 - 1560(3)		-	-	-
B.	-	8.85 - 15(3)	-	-
C.	-	-	-	(DFSS) 20(4)
RECOMMENDED. .	<u>\$1275</u>	<u>\$15.00</u>	<u>\$1500(5)</u>	<u>\$20.00</u>

- (1) Documentation attached. CSA and MOA not differentiated
 (2) No takers at this rate
 (3) Documentation attached
 (4) Verified, 1 party
 (5) Highly speculative

Table 2. Rental price by location in Polk County

Location	Number of tracts	Average size	Average rental per year	Range of rental rates
		Acres	\$/acre	\$/acre
North	8	269.8	8.21	5.88 to 34.29
East Central	5	61.2	6.42	1.50 to 23.08
West Central	20	412.8	9.40	.31 to 30.00
Southeast	18	964.9	4.87	1.00 to 33.33
Southwest	21	162.3	7.54	.62 to 71.43

Rental Rates by Carrying Capacity of the Land

Forty (40) questionnaires reported numbers of animals. The real value of land for pasture is the number of animals it will support. Carrying capacity is not just a measure of the productivity of the land it is also influenced by forage species and pasture management. In addition, fertilization, weed control, rotational grazing, proper stocking rate, among other practices will influence carrying capacity. Cost of renting land, especially for beef production, is better related to carrying capacity (cost per AUM) than cost per acre. Cost of maintaining an animal unit per month or per year is a more objective way of evaluating value than cost per acre.

160 acre pasture supports 40 mature cows with 34 calves and one mature bull for one year.

* (40 cows X 1 AU) 40 X 365 days = 14,600 AUD
 * (34 calves X .25 AU) 8.5 X 180 days = 1,530 AUD
 * (1 bull X 1.6 AU) 1.6 X 365 days = 584 AUD
 Total 16,714 AUD

* 16,714 AUD ÷ 30 days (month) = 557 AUM
 * 557 AUM ÷ 160 acres = 3.48 AUM/acre

* 12 month (year) ÷ 3.48 = 3.45 acres per animal unit

Example of calculating AUM

was then multiplied by number of days each class of animals grazed. This gave the total animal unit days (AUD) for each class of animal. AUDs were added to give total AUDs. The sum of AUDs was then divided by 30 to convert AUDs to AUMs. Total AUMs for the pasture was divided by the number of acres in

Carrying capacity was estimated from the number and class of animals reported on questionnaires along with the number of days each class was grazed. carrying capacity is measured in animal unit months (AUM). An AUM is an estimate of the amount of forage needed to maintain a 1000 lb animal for one month. In our calculations a mature cow was considered one animal unit, a mature bull 1.6, calves .25, yearlings .60, and a horses 1.5.

Carrying capacity in animal unit months (AUM) was estimated by multiplying number of each class of animals by the animal unit (AU) factor. The result

FOR RENTALS (INCL SOME CSA)
Polk County PASTURE LEASES - 1994
RECLAIMED PHOSPHATE LAND - OVER 200 AC

<u>LESSOR</u>	<u>LESSEE</u>	<u>ACRES</u>	<u>ANN. RENT</u>	<u>COMMENTS</u>
		* 1457 ACRES	\$6,045 ⁰⁰ per year OR \$4.15/acre	
		508 ACRES	\$7,270 ⁰⁰ per year OR \$14.31/acre	
		733 acres	\$10,995 ⁰⁰ per year OR \$15.00/acre	
		200 ACRES	\$2610 ⁰⁰ per year OR \$13.05/acre	
		175 ACRES	\$2275 ⁰⁰ per year OR \$13.00/acre	
		600 acres	\$6000 ⁰⁰ per year OR \$10.00/acre	
		223 acres	\$1975 ⁰⁰ per year OR \$8.85 per acre	

AVC. 8 12.37

740 = 11/10/63
 1203 = 10/30/63
 7400 = 10/30/63

* NOTE: Larger lease includes both
 Reclaimed AND non-reclaimed
 LAND - pasture types.

FAX TO MAC (904) 576-7774

COMPLETED SHEET

TABULATION OF SALES

<u>Use</u>	<u>Ag</u> 1	<u>Res</u> 2	<u>Ag (copy right)</u> 3	<u>Comm</u> 4	<u>Rec/Comm</u> 5	<u>Land/Res</u> 6
Sale Number						
Date of Sale	8/88	9/88	10/88	10/87	12/89	3/87
OR/PG	2663-935	2674-546	2684-1338	2581-1032	2810-2018	2517-772
Sec-Twp-Rge	9,15,16-30-24	30-29-24	9,10,15,16-30-25	3-32-25	25,36-29-23	25-28-24 29,30-28-25
Grantor	WR Grace	WR Grace	IMC Fertilizer	Mobil	WR Grace	Agrico
Grantee	Cline	McDonald	Orange Co.	Dynamic Inc.	Int Imp Fund	Polk Co.
Sale Price	\$147,600	\$250,000	\$352,000	\$275,000	\$1,640,100	\$1,750,000
Acres	335.15	180	302.7	114.77	535	1,115
Index Per Acre	\$440	\$1,388	\$1,162	\$2,396	\$3,065	\$1,570
Adjustments:						
Time	Similar	Similar	Similar	Similar	Similar	Similar
Location	Inferior	Superior	Superior	Superior	Superior	Superior
Size	Superior	Superior	Superior	Superior	Superior	Superior
Cond of Sale	Similar	Similar	Similar	Similar	Similar	Similar
Total Adjustment	+\$600	-\$250	-\$200	-\$1,000	-\$2,000	-\$500
Adjusted Index	\$1,040	\$1,138	\$962	\$1,396	\$1,065	\$1,070

% USABLE
RECL. MCA VAL

22% (1)
1120

90% (2)
1280

70% (1)
1560

← NOT APPLICABLE, SPECIAL USE →

1320

(1) PIT AREA DELETED W/ VALUE OF \$250/- AC (2) LOWLAND VALUED @ \$100

SALES (MARKET DATA) INFORMATION

SALE NUMBER: 1

LOCATION: East of Bonnie Mine Road

BRIEF LEGAL DESCRIPTION: Parts of Sections 9, 15, 16, Township
30 South, Range 24 East

OR BOOK/PAGE: 2663/935

GRANTOR: W. R. Grace

GRANTEE: Richard Kline

LAND SIZE: 335.1

ZONING: RC

PROPERTY DATA: 22% usable land with 78% in pits.

PRICE: \$147,600

DATE: 8/88

TERMS: Cash

VERIFICATION: W.R. Grace

PRESENT USE: Mined out land partially reclaimed.

HIGHEST AND BEST USE: Agriculture and recreation.

SALES (MARKET DATA) INFORMATION

SALE NUMBER: 2

LOCATION: South and east of 90° turn in Carter Road, Lakeland,
Florida.

BRIEF LEGAL DESCRIPTION: Part of E-1/2 of Section 30, Township
29 South, Range 24 East.

OR BOOK/PAGE: 2674/546

GRANTOR: W. R. Grace

GRANTEE: Paul D. McDonald

LAND SIZE: 180 acres

ZONING: RC

PROPERTY DATA: This property is estimated to be 90% dry land and
10% low or wet. It has access by easement from Carter
Road. It is reclaimed phosphate land.

PRICE: \$250,000

DATE: 9/88

TERMS: Cash

VERIFICATION: Larry Libertore

PRESENT USE: Vacant

HIGHEST AND BEST USE: Residential/Recreational Development

SALES (MARKET DATA) INFORMATION

SALE NUMBER: 3

LOCATION: East of Orange Co. Plant, south of Bartow, Florida.

BRIEF LEGAL DESCRIPTION: Parts of Sections 9, 10, 15 & 16,
Township 30 South, Range 25 East

OR BOOK/PAGE: 2684/1338

GRANTOR: IMC Fertilizer

GRANTEE: Orange Co.

LAND SIZE: 302.7

ZONING: RC

PROPERTY DATA: This property is 30% pit and 70% reclaimed.

PRICE: \$352,000

DATE: 10/88

TERMS: Cash

VERIFICATION: IMC

PRESENT USE: As a spray field for liquid water from Orange Co.

HIGHEST AND BEST USE: Agriculture

MOA RENTALS (INCL SOME CSA)
POLK COUNTY PASTURE LEASES - 1994
RECLAIMED PHOSPHATE LAND - OVER 200 AC

<u>LESSOR</u>	<u>LESSEE</u>	<u>ACRES</u>	<u>ANN. RENT</u>	<u>COMMENTS</u>
		* 1457 ACRES	\$6,045 ⁰⁰ per year OR \$4.15/acre	
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		200 ACRES	\$2610 ⁰⁰ per year OR \$13.05/acre	
		175 ACRES	\$2275 ⁰⁰ per year OR \$13.00/acre	
		600 ACRES	\$6000 ⁰⁰ per year OR \$10.00/acre	
		223 ACRES	\$1975 ⁰⁰ per year OR \$8.85 per acre	

AVG. 8 12.37

>400 = 11.63
 <400 = 10.35
 >400 10.35

* NOTE: Larger lease includes both Reclaimed AND non-reclaimed LAND - pasture types.

FAX TO MAC (904) 576-7774

COMPLETED SHEET

Appendix C

Biomass Crop Yields and Components

C.1 Herbaceous Biomass Yields

Table 1. Fresh weight and dry matter biomass yields of selected tall grass cultivars at three Florida locations in 1992 growing season.

Tall grass entry†	Plot location‡	Biomass yield				
		Fresh		Dry matter		
		1992	1993	1992	1993	2 year avg
------(Tons/A)-----						
N-51	GA	79.6*	39.9*	26.1*	11.4*	18.8*
PI 300086 eg	GA	88.3*	69.8*	32.3*	19.6*	26.0*
L79-1002 ec	GA	82.9*	39.3*	30.2*	11.4*	20.8*
N-51 eg	EP	29.0	46.9	9.2	13.6	11.4
PI 300086 eg	EP	50.2	34.7	16.9	10.4	13.7
L79-1002 ec	EP	13.6	36.5	4.4	19.5	7.0
S-41 eg	EP	57.5		19.5		
Hexaploid X2 eg	EP	45.4		15.4		
US 72-1153 ec	EP	44.8	60.1	11.6	19.8	15.7
124-A-6 seeded eg	EP	38.1		12.6		
US 56-9 ec	ML	57.8	45.3	18.3	14.4	16.4
US 78-1009 sc	ML	67.1	68.8	17.1	17.5	17.3
CP72-1210 sc	ML	49.5	48.1	13.4	13.0	13.2
L79-1002 ec	ML	50.5	42.7	16.9	14.2	15.6
US 72-1153 ec	ML	73.0	63.2	17.8	15.4	16.6
1K 7647 er	ML	49.5	22.4	11.4§	5.1§	8.3§
N-51 eg	ML	28.6	28.8	8.3§	8.3§	8.3§
US 67-2022 sc	ML	88.7*	74.0*	24.0*	20.1*	22.1*
Grassle (ratoon)	ML	13.9		3.2		

† eg = elephantgrass, sc = sugarcane, ec = energycane and er = erianthus and s = sorghum.

‡ Location: GA was Green Acres Agronomy Farm near Gainesville, FL; EP was Energy Park on University of Florida campus at Gainesville, FL; ML was on phosphatic clay at Mined Lands Agricultural Research/Demonstration Project headquarters in Polk County, FL.

* Plots were not bordered by plants of equal size so environmental enrichment, especially for light, occurred.

§ Poor plant stand.

C.2 Herbaceous Biomass Chemical Composition

Table 2. Average chemical composition of oven dry biomass from the various tall grass crops over genotypes, locations and 1991 and 1993 growing seasons.†

Tall grass crop	No. of samples	Chemical composition						
		CP	NDF	ADF	H-CELL	CELL	LIG	IVDMD
		----- % -----						
Elephantgrass	13	6.9	74.59	46.68	27.95	39.47	7.06	44.36(8)‡
Erianthus	2	4.73	74.72	48.08	26.64	40.81	7.20	45.66(1)
Energycane	12	5.27	72.78	45.00	27.78	37.64	6.60	49.52(6)
Sugarcane	6	4.56	60.75	37.44	23.31	31.84	5.64	53.77(3)

† This table summarizes data from different crops and locations shown in Table 1.

‡ No. of samples in value when less than total number of samples for crop.

C.3 Woody Biomass

NREL "ECONOMIC DEVELOPMENT THROUGH BIOMASS SYSTEMS INTEGRATION IN CENTRAL FLORIDA" PROJECT: Preliminary Final Report for Tree Biomass Component

prepared by

D. L. Rockwood
School of Forest Resources and Conservation,
University of Florida

General. Administration and conduct of this project component were discussed with NREL representatives at Gainesville on June 30 and at Bartow on November 15-16. Tree biomass options were also discussed with growers and environmental representatives in Bartow on March 1, 1995.

Specific activities for the Tree Biomass Component were conducted as Tasks #2b and #4b of the overall project. Associated timelines for performance and budget are shown in NREL-formatted figures following the report.

Task #2b Identify crops to be grown and associated production practices: Tree Biomass

A. Procedure/Data. The potential for developing woody biomass production systems on native and reclaimed lands in the central Florida phosphate mining region was documented by drawing upon research completed or in progress in peninsular Florida. As possible for Eucalyptus grandis (EG), E. camaldulensis (EC)/E. tereticornis (ET), E. amplifolia (EA), slash pine and Sapium sebiferum, production functions based on planting stock type, planting density, site/culture, and age were generated, and the most realistic production options (including planting stock type and cost, planting density, site, cultural option, rotation age, and season of harvest) were developed to estimate yields. Phosphate lands classifications and extent were obtained from Task 2a.

B. Deliverables/Products. For each tree crop, field operations and anticipated yields were tabulated and given to Tasks 2c, 7a, 7b, and 7c; harvesting possibilities, desired processing, and operational constraints were provided to Tasks 2d, 7a, 7b, and 7c; and yield per acre and cost of production were distributed to Tasks 2f, 2g, 2h, 7a, 7b, and 7c. Task 7b was appraised of risk factors associated with tree crops. These data are presented in tables found in the Tasks 2 and 7 sections of the final report.

In August 1994, site preparation and planting options were discussed with equipment contractors. For example, Frank Osteen of Fort White demonstrated equipment prototypes for preparation of clay settling ponds and estimated costs of \$10, 10, and 15/acre for trenching, filling, and bedding components of site preparation and \$50-55/acre for planting. Osteen is available in 1995 for a demonstration/test of equipment at the Mined Lands Center. In September 1994, this component obtained a catalog of tree planters from a equipment manufacturer to assess planting options for mined lands.

EA stem biomass samples were provided to Task 6b on June 12 and December 23, 1994, for fermentation analyses and to Task 6c on June 12 and 30, 1994, for combustion analyses. Combustion analyses indicated 3.2% ash, .23% sulfur, .54 lb. of SO²/million BTU, 8,437 BTUs/lb., and .32% chlorine on a dry weight basis for the first sample and 2.2% ash, .15% sulfur, .36 lb. of SO²/million BTU, 8,221 BTUs/lb., and .32% chlorine for the second sample. The fermentation analyses are reported elsewhere.

Task #4b Expand Seed Stock Plantings: Tree Biomass

A. Procedure/Data. Progenies and clones in existing genetic tests in central and southern Florida were assessed to identify superior genotypes for commercial use. In August 1994, a clone bank of three Eucalyptus species was established on a one-acre site on a clay settling pond at the Mined Lands Center, with site preparation and maintenance provided by Mined Lands Center equipment and personnel. In January 1995, 51 EG, 21 EC, and three ET clones in south Florida field trials were felled for propagation by rooted cuttings to establish a second clone bank at the Mined Land Center. Some 80 EA at three sites were also girdled in March for the same purpose. Seed were collected from superior trees in existing advanced-generation seed orchards of EG, EC, and ET.

B. Deliverables/Products. Three EG (141 - 253 ramets each), four EC (66 - 120 ramets each), and five EA (1 - 9 ramets each) clones were planted on August 19 and 29; another 10 EA (1 - 3 ramets each) clones were added in January 1995. Through January, individual trees planted first were up to 2m tall, with EC clones having the greatest overall vigor (Table 1). A freeze in February did not damage any trees. Altogether, these plantings assembled nearly 1,000 trees for possible production of rooted cuttings. Soil analyses for the clone bank suggested that clay settling ponds have very adequate nutrient levels for Eucalyptus but may need N amendments for desirable nutrient balance.

Table 1. January 1995 height (m) and survival (%) of Eucalyptus species and clones planted at the Mined Lands Center through January 1995.

Species	Planted 95/08/19			Planted 94/08/29			Planted 95/01/05	Total No.
Clone	no.	Height	Surv.	no.	Height	Surv.	no.	Planted
EA	15	0.88	87				20	35
4878							1	1
4879	9	1.02	89				1	10
4895							3	3
4914							2	2
5025	2	0.53	100				2	4
5029							1	1
5045	1	0.11	100					1
5046	2	0.78	50					2
5063	1	1.34	100				2	2
5076							1	1
5085							1	1
5101							3	3
5115							1	1
5117							2	2
EC	132	1.17	86	273	0.75	68		405
4543	35	1.41	97	71	0.91	87		106
4544	30	1.21	87	83	0.79	76		113
4583	37	1.04	76	29	1.21	72		66
4590	30	0.99	83	90	0.44	46		120
EG	208	1.11	84	328	0.49	51		536
2798	48	1.16	90	93	0.23	32		141
2805	87	1.09	85	55	0.41	53		142
2817	73	1.09	78	180	0.64	61		253

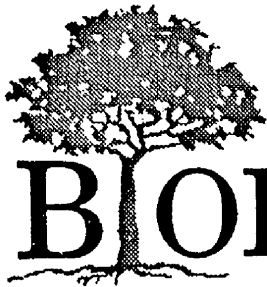
The second Eucalyptus clone bank at the Mined Lands Center is scheduled for planting in July 1995. Collectively, the two clone banks are expected to produce 100,000 cuttings annually.

The best Eucalyptus clones can be propagated vegetatively by rooted cuttings, by micropropagation, or by seed. In December 1994, Eucalyptus macroprogagule, micropropagule, and seedling propagation options were discussed with Twyford International, Inc., in Apopka, Florida. From September to November 1994, seed was collected from 22 EG and seven EC seed orchard trees and processed (Table 2). The total of over 3.4 kg of seed consisted mainly of EG. The seed crop available for EG in Spring 1995 was heavy; abundant quantities of seed capsules were collected in March/April from more than 100 seed orchard trees. After processing, several kg of seed should be in storage. No seed was obtained for Sapium sebiferum, as this exotic species is considered to be too invasive for commercial use.

Table 2. Eucalyptus seedlots collected in 1994-95.

Species: <u>Accessiion</u>	<u>Collection Date</u>			<u>Total Amount</u> (g)
	<u>94/09/20</u> (g)	<u>94/10/11</u> (g)	<u>94/11/07</u> (g)	
EC:				294
2631	18			18
2668	64			64
2690	24			24
2697	12			12
2716	46			46
2720	22			22
2748	109			109
EG:				3144
908			471	471
911			16	16
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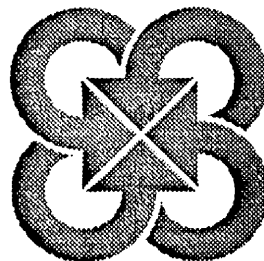
**C.4 Woody Biomass Production in Waste
Recycling Systems**



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WOODY BIOMASS PRODUCTION IN WASTE RECYCLING SYSTEMS

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ABSTRACT

Combining woody biomass production with waste recycling offers many mutual advantages, including increased tree growth and nutrient and water reclamation. Three biomass/recycling studies collectively involving Eucalyptus amplifolia, E. camaldulensis, and E. grandis, rapidly growing species potentially tolerant of high water and nutrient levels, are 1) evaluating general potential for water/nutrient recycling systems to enhance woody biomass production and to recycle water and nutrients, 2) documenting Eucalyptus growth, water use, and nutrient uptake patterns, and 3) identifying Eucalyptus superior for water and nutrient uptake in central and southern Florida. In a 1992-93 study assessing the three Eucalyptus species planted on the outside berms of sewage effluent holding ponds, position on the berms (top to bottom) and genotypes influenced tree size. The potential of the trees to reduce effluent levels in the ponds was assessed. In a stormwater holding pond planted in 1993, these Eucalyptus genotypes varied significantly for tree size but not for survival. E. camaldulensis appears generally superior when flooded with industrial stormwater. Potential sizes of ponds needed for different stormwater applications were estimated. Prolonged flooding of 4- and 5-year-old E. camaldulensis with agricultural irrigation runoff has had no observable effects on tree growth or survival. Younger E. camaldulensis, E. amplifolia, and E. grandis were assessed for water use and nutrient uptake during a Summer 1994 flooding.

INTRODUCTION

Florida is a large energy importer, and woody biomass energy crops have considerable potential for meeting local energy needs (1). Within the state, several opportunities exist for enhancing woody biomass production while addressing other critical concerns.

Treatment of urban generated wastewater is one such opportunity. Sewage effluent produced by a rapidly expanding population must have nutrients removed to meet water quality standards, and various woody species respond vigorously to the nutrients in effluent. Urban and industrial stormwater presents additional recycling challenges, such as removal of heavy metals, which may be accomplished by tree species. Effluent and stormwater impacts on water quantity may be reduced by utilizing trees' evapotranspiration (ET) potential.

Purification of nutrient laden water from agricultural operations is another general area of opportunity. Sustainable agriculture in the Everglades Agricultural Area (EAA, a 260,000 ha

area of organic soils south of Lake Okeechobee including Belle Glade, Florida) may be possible if flood tolerant crops in large demand can be developed (2). Since the early 1900s when 92% of the EAA had soils more than 1.5m deep, soil subsidence resulting from drainage has averaged 3cm/year and now threatens agricultural production of \$750 million annually. By 2000, 45% of the EAA is predicted to have soils less than 0.3m deep over bedrock, approaching a depth too shallow for conventional production methods. The only feasible way to stop subsidence is to keep the soils flooded, or at least to maintain a very high water table, for a substantial portion of the year. Water tolerant woody biomass energy crops could help in dealing with water quantity and quality as well as producing energy feedstocks for the area.

Several Eucalyptus species have shown high levels of productivity in woody biomass production systems (1). Eucalyptus amplifolia is freeze hardy enough to be grown on agricultural quality lands throughout peninsular Florida, but no proven clones are yet available. E. camaldulensis has a wide site tolerance in central and southern Florida, and numerous clones have been developed for California and Florida. E. grandis grows very well on sandy and organic soils in southern Florida, and freeze-resilient clones have been selected.

PROCEDURES

To estimate their wastewater recycling potential in Florida, these Eucalyptus species were established in 1992-93 at Zephyrhills (Forest Lake Estates), Tampa (Tampa Port Authority), and Belle Glade (Everglades EREC) as up to 36 progenies and 14 clones of E. amplifolia, 13 clones and two progenies of E. camaldulensis, and four clones of E. grandis (Table 1).

At Zephyrhills, a total of 36 progenies and two clones of E. amplifolia, 10 E. camaldulensis clones, and three E. grandis clones were planted from 1992 to 1993 on holding pond berms to assess the species' potentials to "pump" sewage effluent from ponds. At Tampa, 11 progenies and 12 clones of E. amplifolia, seven E. camaldulensis clones, and four E. grandis clones were planted in June 1993 in a 0.6ha stormwater holding pond to recycle industrial stormwater applied as overland flow; stormwater applications were begun in June 1994. At Belle Glade, seven E. amplifolia progenies, seven E. camaldulensis clones, and three E. grandis clones were planted in June 1993 to recycle agricultural irrigation runoff applied by periodic flooding; the first flood was initiated July 15, 1994. Also at Belle Glade, two E. camaldulensis progenies planted in November 1988 were flooded with irrigation runoff from August to November 1993 to estimate flooding tolerance.

Quarterly tree growth, periodic climatic data, and amendments were monitored, as possible, and compiled across the three plantings to identify the most effective species/genotypes and to estimate recycling potential. In April 1994 at age 24 months, 24 E. amplifolia trees at Gainesville were felled, weighed, and dried to develop biomass predictive equations and to estimate nutrient contents. Leaf nutrient sampling was done in the Belle Glade study in April 1994 and in all studies in June 1994. Installation costs for the Tampa project (constructing the holding pond and planting of trees) were tabulated. Guidelines for establishment of woody biomass waste recycling systems were developed.

RESULTS

At Zephyrhills, position on the pond berms and genetic variation strongly influenced tree size.

Table 1. Mean height (m) of *Eucalyptus* progenies and clones in three waste recycling studies.

Species:	Zephyrhills	Tampa	Belle Glade	Species:	Zephyrhills	Tampa	Belle Glade
Genotype	(26 mos.)	(12 mos.)	(12 mos.)	Genotype	(23 mos.)	(12 mos.)	(12 mos.)
<i>E. amplifolia</i> Progenies:				<i>E. amplifolia</i> Clones:			
4809	4.2a-e ¹	2.0f-g		4879		2.4b-g	
4814	4.1a-e		1.5abc	4881		1.8gh	
4823	4.2a-e	2.2c-g	3.5cd	4896		2.1e-g	
4827	5.5ab		1.1bc	4899		2.7a-e	
4842	3.7c-e			4900		2.0f-g	
4854	5.7a			4930		2.2d-g	
4859	4.4a-e	2.0f-g		4934		2.3c-g	
4861	3.4c-e			4941	1.9bc	2.0f-g	
4862	4.6a-d	1.4f-g		4942		2.4a-g	
4869	3.5c-e			4945		2.4c-g	
4870	3.9b-e			5025		2.1f-g	
4871	3.2c-e		1.1bc	5028		2.0f-g	
4872	3.6c-e			5029		2.3c-g	
4873	3.0de			5030	1.9c		
4874	3.3c-e			Average	1.9	2.2B	
4875	2.9e		1.6abc	<i>E. camaldulensis</i> Clones:			
4876	3.7c-e			4543	3.6a-c		
5010	3.5c-e			4544	3.2a-c		
5011	3.7c-e			4580	4.0a	2.5a-g	4.2bcd
5012	4.1a-e		1.0c	4581			
5013	3.3c-e			4582		3.0ab	4.3bcd
5014	4.8a-c	2.3c-g	4.5abc	4583	3.7ab	2.5a-g	4.2bcd
5015	4.6a-e			4584		2.9a-c	3.1d
5016	3.6c-e			4585	3.2a-c		
5017	4.9a-c			4586	3.5a-c		
5018	4.9a-c			4587	3.7ab	2.8a-d	3.0d
5019	3.3c-e			4588	3.5a-c		
5020	3.6c-e			4589	4.3a	3.1a	3.4cd
5021	4.3a-e	2.0f-g	4.2bcd	4590	3.9a	2.8a-d	4.6abc
5022	4.3a-e			Average	3.4	2.8A	4.5A
5023	3.8c-e			<i>E. camaldulensis</i> Progenies:			
Average	4.0						(66 mos.)
	(14 mos.)			C-19			8.8b
5040	1.7b	1.9f-g	3.6cd	C-20			13.6a
5041	3.6a	2.0f-g	4.2bcd	Average			11.7
5042	2.1a-b	1.9f-g			(11 mos.)		
5043	2.3ab	2.2d-g	5.7a	<i>E. grandis</i> Clones:			
5044	2.4ab	2.1e-g	5.4a	2798	2.9a-c	2.0f-g	3.0d
Average	2.4			2805		2.2c-g	
				2814	3.3ab	2.1e-g	5.9a
Average		2.0B	3.9A	2817	4.0a	2.5a-f	5.7a
				Average	3.4	2.2B	5.2 A

¹ Progenies/clones not sharing the same lower-case (and, in the Tampa and Belle Glade studies, species the same upper-case) letter are significantly different at the 5% level

Trees at the top of the berms were 1m and 2.6m taller, respectively, in the cases of *E. amplifolia* and *E. camaldulensis* after approximately two years (Table 2). Trees next (1.5m) downslope tended to be second largest, while trees further down the berms were of similar size. Generally, the soil/water environment at the top of the berms was more favorable for rapid tree growth beginning at age 8 months.

The berm position influence is suggestive of the trees' potential to "pump" sewage effluent from holding ponds. Within a year of planting (assuming vegetation control) on pond berms within 2m of the pond edge or water level, *E. amplifolia* and *E. camaldulensis* should begin to uptake effluent. *E. camaldulensis* seems more capable of rapidly accessing and using the effluent. Exact levels of water use have yet to be determined for these species in Florida; while the greater leaf biomass of *E. amplifolia* would appear to give it an edge in ET potential, the high water uptake noted for *E. camaldulensis* in Australia suggest that some of the *E. camaldulensis* clones may have the highest uptake potential, most likely near the limits set by Florida's climate.

The *E. amplifolia* progenies and *E. camaldulensis* clones differed considerably in growth after two years (Table 1). At 26 months of age, the *E. amplifolia* average height was only 4m, a reflection of the generally infertile, poorly drained soils in the berms. The 31 progenies planted in 1992 varied considerably, with the tallest progeny (5.7m) nearly twice the height of the shortest progeny (2.9m). Individual trees were over 8m tall and 10cm in DBH. The slightly younger *E. camaldulensis*, California selected clones being tested for the first time in Florida, were more uniform and averaged an impressive 3.4m tall growing on a heavy clay part of the berm that was brick-like when dry. The tallest *E. camaldulensis* was over 7m; while these clones often were similar in height to *E. amplifolia*, they usually had lower DBH-height ratios. The *E. grandis* clones, especially Clone 2817, grew very rapidly on a favorably situated part of the berm during their first year and should be taller at the end of their second growing season, in the absence of freeze damage, than the best *E. amplifolia* or *E. camaldulensis* were.

At Tampa, genetic variation had strong influences on growth. After one year, the *E. camaldulensis* clones were taller than the *E. amplifolia* progenies and clones and the *E. grandis* clones (Table 1). On this nutrient poor, slightly saline soil (bay dredgings), all of the *E. camaldulensis* clones exceeded virtually all of the other genotypes. *E. grandis* Clone 2817 again was the best of its species, while Clones such as 4899 may be emerging as the best *E. amplifolia* genotypes. All trees responded well to fertilization and mulching in February 1994 (as well as apparent subsequent root extension to the 1m deep water table) and were equally healthy prior

Table 2. Effects of berm planting position on height and survival of 26-month-old *E. amplifolia* and 23-month-old *E. camaldulensis* at Zephyrhills.

Berm Position	<i>E. amplifolia</i>		<i>E. camaldulensis</i>	
	Height (m)	Survival (%)	Height (m)	Survival (%)
1(=Top)	5.1a	74a	5.8a	100
2	4.1b	89a	3.2b	100
3	3.9bc	85a	3.0b	92
4	3.6c	90a	2.7b	92
5	3.7bc	82a	3.1b	83
6 (=Bottom)	3.7bc	79a	2.1b	75

¹ Treatments not sharing the same letter are significantly different at the 5% level

to the first application of stormwater via overland flow this summer.

The performance of E. camaldulensis to date suggests that it will do best in flooded situations such as the Summer 1994 stormwater applications. During inundations lasting several weeks due to heavy rains in late Summer 1993, it was the only species that appeared unaffected.

At Belle Glade, species differences were nonsignificant after one year, but the E. amplifolia progenies, E. camaldulensis clones, and E. grandis clones ranged considerably in size (Table 1). E. amplifolia tended to be smaller, although progenies 5043 and 5044 were among the larger genotypes in the study. E. camaldulensis was intermediate in height but tended to be smaller in DBH and to have poor stem form. The E. grandis clones 2814 and 2817, as expected from previous studies, were the most vigorous genotypes, reaching as much as 7m in height, but clone 2798 was exclusively attacked by the foliage-eating insect Anomala marginata and was consequently one of the shortest genotypes. Therefore, prior to the first flooding of these trees in July 1994, any possible flooding tolerance advantage due to tree vigor was with perhaps five of the progenies/clones in the study.

The expected greater flood tolerance of E. camaldulensis was evidenced by the two 66-month-old progenies flooded with agricultural irrigation runoff in 1993 (Table 1). The 3-month inundation beginning in August caused no mortality and did not detectably inhibit tree growth during or after the flooding. The 19m height achieved by the best trees in C-20, the better progeny, illustrates the tree size that should be routinely achievable on muck soils within five years with the best E. camaldulensis clones. Such vigorous growth combined with flooding tolerance should maximize water and nutrient uptake.

Genetic variation at the between and within species levels is important in realizing maximum productivity in various applications and areas. In northern and central Florida, proven E. amplifolia, and the best clones in particular, can produce up to 25 dry mt/ha/year on agricultural or amended sites (3). In central and southern sections, E. camaldulensis clones offer tolerance to flooding. Some E. grandis clones can yield as much as 35 mt/ha/year when freeze, and perhaps flooding, are not limiting factors. In all three eucalypts, identification and use of frost-tolerant individuals is possible.

The EAA climate is generally representative for the three study sites. Most of the long-term average of 1,400mm of annual rainfall occurs during the summer, and the winter tends to be dry. Considerable variation occurs around these averages, however. Pan ET, which varies relatively little from year to year, exceeds rainfall by about 200mm annually on a long-term basis. Although ET is highest during the summer, it typically exceeds rainfall only from October through May (Figure 1).

The exact amount of water and nutrients taken up by the Eucalyptus species in these recycling systems will depend on climatic limits, tree vigor, and the timing and extent of the wastewater applications. Pan ET in Florida, about 1,600mm annually, is less than the levels of ET reported for Eucalyptus elsewhere. The maximum ET observed for vigorous aquatic plants in Florida is 80% of pan ET. Irrigated Eucalyptus may use up to 30% more water than short grasses when their leaf canopy completely covers a site (4), but their relative consumption in Florida is yet to be established. The vigorous E. grandis at Belle Glade achieved complete canopy closure after one year when planted at 4,444 trees/ha. Documented annual nutrient accumulations in irrigated woodlots in Australia are 90, 15, 60, 95, 20, and 25 kg/ha for N, P, K, Ca, Mg, and Na, respectively (4). Extrapolating from previous studies (5), two-year-old E. grandis on EAA

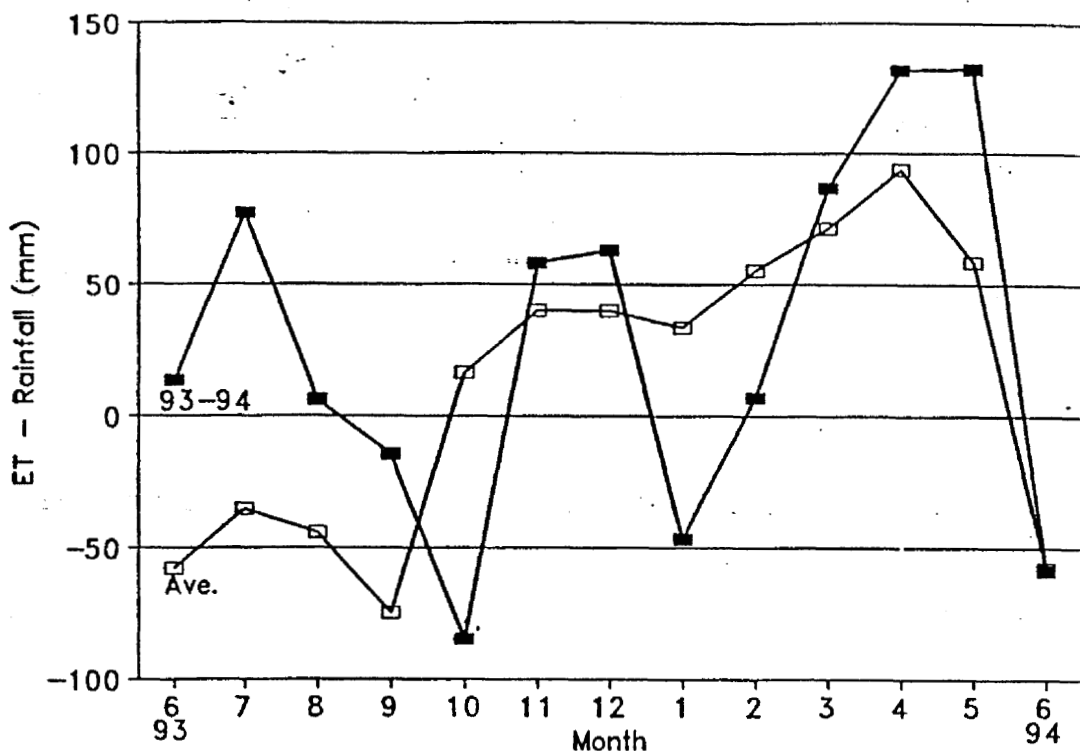


Figure 1. Evapotranspiration - rainfall for 1993-94 and for long-term at Belle Glade.

organic soils are expected to exceed these N, P, K, and Mg levels and to approximate the Ca level on a whole tree basis. Harvesting of trees without foliage is projected to remove about 30, 30, 60, 30, and 10 kg/ha/year for N, P, K, Ca, and Mg, respectively. Because vigorous trees are required to achieve or maintain these levels of water and nutrient use and the time and duration of wastewater application in the three systems is expected to impact the Eucalyptus species/genotypes differentially, identifying the most flood-tolerant clones is essential.

These "pilot" recycling systems offer guidelines for the establishment of larger-scale woody biomass waste recycling systems. Sewage effluent pond berms could be easily and inexpensively converted from typically grass cover to tree cover. The amount of lowering of effluent levels in the ponds by the trees depends, however, on several factors: excess of ET over rainfall, amount of berm occupancy by the trees, tree access to the effluent, and the ratio of berm area to pond area. In the Zephyrhills case, about 0.34 ha of trees are planted around some 0.55 ha of ponds. Should the Eucalyptus use effluent for a surplus 200mm of ET, the effluent in the ponds would be drawn down by 125mm a year. Larger ratios of berms to ponds would of course increase the drawdown, and smaller ratios would decrease it.

The Tampa stormwater recycling system (6) is predicated on 100% treatment of the "first flush" (1.27 cm) of stormwater runoff events when the average annual rainfall is 1,270 mm/year. At \$9,000 for retrofitting a 2.22 ha stormwater discharge basin to capture and deliver 282m³ of stormwater to the holding pond, the cost of this industrial facility retrofit was approximately \$4,000/ha. Since over 50% of this cost was the forcemain for delivery, the cost/ha would be less for larger facilities. With the .61 ha holding pond costing \$14,000 for all construction and tree establishment activities, the \$23,000/ha cost in this case should drop considerably for larger holding ponds. The resulting installation cost for this Eucalyptus stormwater recycling retrofit,

\$27,000/ha of stormwater discharge basin, should decrease somewhat in proportion to the size of larger scale installations. At full evaporative capacity (tree age of approximately four years), the trees in the .61 ha pond are expected to dissipate between 50 and 87m³ on an annualized daily basis. Thus, one ha of holding pond is projected to recycle at least 80m³ of stormwater daily.

The irrigation runoff system used for the Belle Glade study is a low-cost recycling option but may not be very effective under the "pond" design and tree sizes of 1993-94. With existing irrigation equipment, the only cost was for construction of .5m "berms" around the "pond". The porous muck soils though allow runoff pumped in to seep out, and the young trees might not have transpired the maximal amount. Larger "ponds" could be formed relatively inexpensively by creating impermeable dikes. A delivery system would need to be constructed to deliver the runoff to the high end of a field, and an outflow structure would be needed at the end.

Excess water in the EAA is now drained off most crops during the summer, but there are few acceptable reservoirs. The nutrients which have been linked to deterioration of the Everglades, particularly P, are thus discharged primarily in the summer. By retaining the water on tree crops during the summer, beginning in July or August, and discharging it during the drier periods, starting about November or December when additional water is needed, some P removal is likely to occur, and this serious water management problem might be alleviated. Unlike true aquatic crops, Eucalyptus have no absolute demand for flooding during the dry season. In fact, the dry winter is the ideal time for harvesting the trees with most assurance of successful coppicing.

It is estimated that as much as 10% of the EAA could be cropped with Eucalyptus in the near future. The "Everglades Forever" Act requires that 16,000 ha of marsh be created publicly to filter P from agricultural runoff, and farmers may need to create additional filter areas on private land to meet water quality standards to permit discharge into public lands. Thus, flood tolerant tree crops grown on a portion of the EAA could have many benefits. The natural features of the wetland could be retained, resulting in sustainability of the soils, reduced nutrient discharge, and feedstocks for two electrical generation plants near Belle Glade. If growers are forced to dedicate a portion of their land to water treatment reservoirs to remove P prior to discharge in public canals, woody biomass crops could be financially and environmentally rewarding.

In addition to the recycling and energy feedstocks benefits possible through woody biomass production, Eucalyptus species can provide landscape mulch and pulp and paper. Florida-produced Eucalyptus mulch is marketed throughout the eastern United States as a highly desirable alternative to cypress mulch. Several Eucalyptus species are preferred for making fine quality papers (3). Harvesting of Eucalyptus for any of these products effectively removes nutrient accumulations from the production site.

These conclusions on best Eucalyptus species/genotypes, water/nutrient uptake, and system design are preliminary in nature. The data to be obtained following Summer 1994 will likely indicate trends. Each study, though, needs to be continued for a full rotation or more; for Zephyrhills, Tampa, and Belle Glade, these durations should be at least four, four, and two years, respectively. Specific assessment of water use is needed, and biomass production rates must be documented.

CONCLUSIONS

For wastewater recycling in Florida, Eucalyptus species have potential for effectively recycling

sewage effluent in ponds or applied by spray and industrial stormwater or agricultural irrigation runoff applied by flooding. *E. amplifolia* can grow over 4m per year on good sites throughout the state. Within a year of planting near water, *E. amplifolia* and *E. camaldulensis* uptake effluent. *E. camaldulensis* more rapidly accesses and uses effluent and may do best in flooded situations. *E. grandis* clones also grew very rapidly. *E. amplifolia* progenies and clones, *E. camaldulensis* clones, and *E. grandis* clones often differed considerably in growth and flood tolerance. By combining these performances with artificial freeze test results, the best genotypes for wastewater recycling systems can be identified.

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C.5 Leucaena: Energy and Forage Crop

Leucaena: Energy and Forage Crop
for Lower South USA

G. M. Prine and T. V. Cunilio

This report was prepared to give background information
and management practices for leucaena as a bioenergy
crop under NREL Project 2AU-4-13326-05.

Leucaena, Energy and Forage Crop for Lower South USA

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INTRODUCTION

This production guide deals with leucaena grown primarily for biomass production in short rotation intensive culture plantations (SRIC). It will also focus on production on the reclaimed settling pond soils of Polk and Manatee Counties in Central Florida. These soils are considered available and ideal for energy crops such as leucaena after 10 years of experience at the Mined Land Agricultural Research/Demonstration Project. However, leucaena is also suitable for many other geographic and ecological zones of Florida and the Lower South where the crop is useful for both forage and energy.

We have searched the literature on leucaena and attempted to bring pertinent information on growth and production of this crop into this report. Because leucaena is essentially a new crop in Florida, it is discussed in detail giving background information on all phases of leucaena production and management and uses. The references used here are cited using the principal author's or institution's name and the year of publication. Many references cite personal communications and unpublished data which indicate, in a real sense, the unpolished and incomplete nature of leucaena research and literature in Florida. By reading this report, one should obtain up-to-date information on leucaena as a new crop in Florida and the Lower South.

CHAPTER 1 WHAT IS LEUCAENA?

1.1 Description: *Leucaena* is described as a perennial, woody legume tree or shrub which regrows each spring from below ground rootstock in colder, subtropical and warm temperate climates where temperatures below -2°C (28°F) occur (Cunilio and Prine, 1991). The name *leucaena* is the accepted name for the one species *Leucaena leucocephala* (Lam.) de Wit., but it is also the name of the genus that includes 14 other species (Sorenson, 1994). *Leucaena* is a member of the sub-family Mimosoideae of the family Leguminosae, a family of some 18,000 species. *Leucaenas* are noted for their ability to fix atmospheric nitrogen through symbiosis with rhizobium bacteria in forms available as nutrients to the growing plants. Most of the fixed nitrogen is found in the leaves as protein (van den Beldt, 1985).

1.2 Origin and Distribution: *Leucaenas* are found endemic across a 7,000 km range from Peru northward to Texas (Sorenson, 1994). It has been identified in Florida since at least the 1930's and more than likely was introduced in the peninsula from its center of origin in Central America and Mexico by traders. *Leucaena* was transferred to Asia from W. Mexico in the 16th and 17th centuries at the time of the galleon trade. It became a popular feed or forage plant in the 19th century and later a shade tree for coffee, cacao and other plantation crops (Brewbaker, 1985). Today, *leucaenas* may be found in almost all tropical countries especially on soils derived from limestone on islands where it often dominates the vegetation (van den Beldt, 1985).

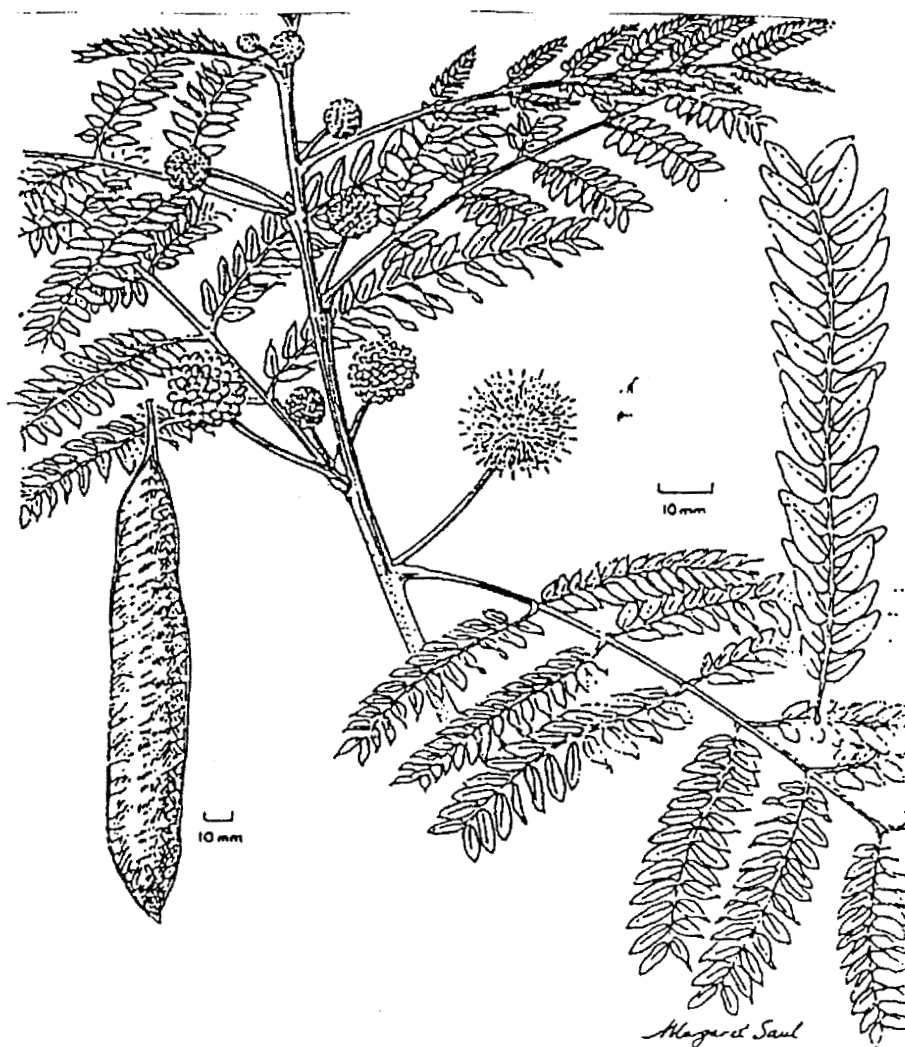
1.3 Appearance: The *leucaenas* used for energy are tall and are known as giant or Salvador type to distinguish them from the bushy, common type and the intermediate Peru type (NAS, 1984). On good sites in Florida, the giants grow rapidly to 10 meters (30–32 ft) in 4–5 years. In north Florida, a Salvador type (K8) reaches 7–8 meters (20–24 ft) in height each year before being killed by frost (Cunilio and Prine, 1991). The common or Hawaiian *leucaena* is a short tree or branching shrub growing to 2–3 meters (10 ft) in South Florida (Kalmbacher, 1994). Differences in total height following winter kill between giant and common types in a Gainesville *leucaena* collection have not been generally evident but stem diameters have differed (Cunilio, 1994). In general, mature *leucaenas* reach 5–20 meters in height and 5–70 cm in diameter at breast height (NAS, 1984).

The leaves of all *leucaenas* are bipinnately compound bearing 3–50 short branches (pinnae) 8–15 mm in length with 4–160 pairs of leaflets (called pinnules) per pinna depending on the species. The small leaflets range in shape from ellipses to teardrops. The major vein is inserted off center at the leaflet base (Fig 1.1). All the common *leucaenas* have a grey, waxy bloom on the young leaves (Brewbaker, 1994). In extreme drought, the leaflets fall off. None of the *leucaenas* are thorny. *Leucaenas* produce dense, globular, and in all but two species, white flowers which produce brown, flat pods that hang in clusters. Pods and seeds of the giant types are much larger than those of the common (van den Beldt, 1985). Seed from several giant types produced in Florida range from 7,000 to 9,000 seed/lb (Cunilio, 1994). *Leucaena* flowers are self fertile but up to 5% outcrossing can occur with compatible genotypes (Kang, 1994).

1.4 Uses: *Leucaena* is used for biomass (wood), browse for cattle, green chop for dehydrated range cubes, as green manure and in erosion control (NAS, 1985). A discussion of its use as a fodder can be found in Chapter 9. In SRIC plantations, where wood is the primary product, leaf drop may accumulate in the soil from winter to winter or from dry season to dry season providing nutrients which will be recycled. Such soil manuring provides an excellent medium for a decidedly small number of secondary crops. This practice is used especially in the less developed countries and is one of many permutations of agroforestry (Nair, 1993).

FIG. 1.1

Leaves, flower and pod of *Leucaena leucocephala*



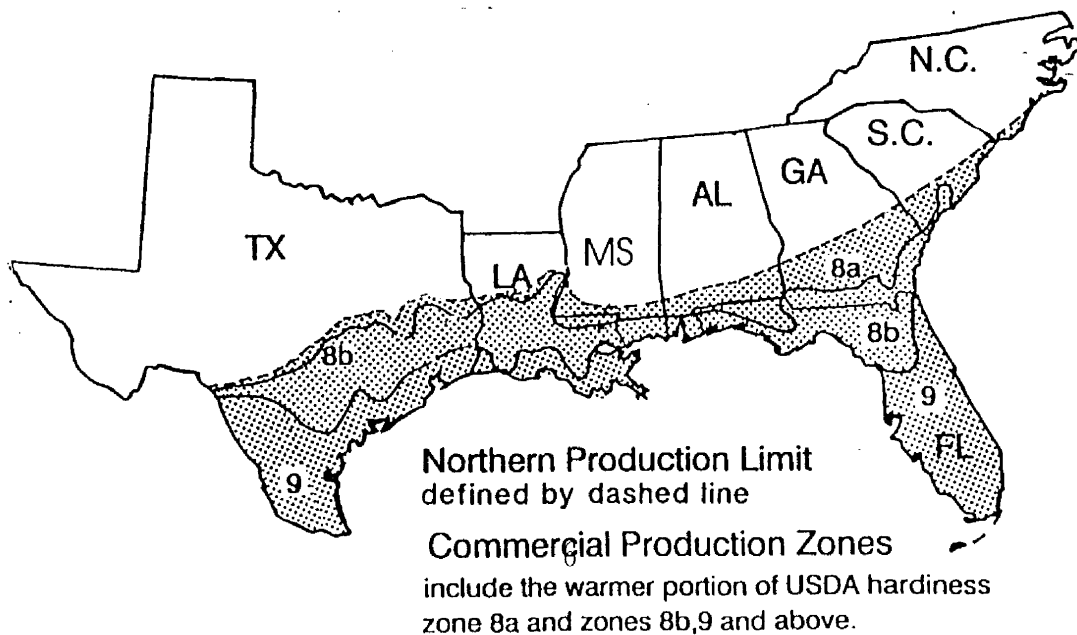
CHAPTER 2 WHERE IS LEUCAENA GROWN?

2.1 Soil Type: Leucaena's roots can reach deep for nutrients and water and allow the plant to tolerate a wide array of soil conditions. Leucaena is found thriving in soils with textures varying from stony soils to heavy clay and coral. Unaided, leucaena grows well only in neutral or slightly alkaline soils, growing best at pH 6.0 – 7.7. Surface and especially subsoil acidity (at 50–200 cm depth) must be assessed if difficulties in growing leucaena (slow growth and stunted roots) are to be avoided (NAS, 1984). Nevertheless, good management will allow leucaena to thrive in field hedgerows or nurseries even where native soil is above pH 5.0. Optimum soil conditions are well-drained alkaline soil with pH of 5.5 – 8.5 and with a reasonable mineral balance, especially for phosphorous, calcium, molybdenum and zinc (Brewbaker, 1980). There are a few leucaenas which have been bred to grow in strongly acid soils (van den Beldt, 1985). A fuller discussion of cultivars and management practices is presented in Chapters 3 and 5 of this production guide.

The principal soil physical requirement for leucaena is drainage. Leucaena cannot tolerate "wet feet" year round, i.e., where standing water is the norm (NAS, 1984; Kang, 1994). It will grow well in the seasonally dry soils of South Florida, especially when planted on ridges or in the dryer spring or fall months of March, April and May or September and October (Kalmbacher, 1993). Although drainage to avoid standing water will help sustain high yields, poor drainage after establishment will not result in the death of the plant (NAS, 1984). If there are several weeks of low rainfall where the water table is below 1 meter (3 feet), leucaena can do well (Cunilio, personal communication). In fact, it is this drought tolerance which makes leucaena well suited for seasonally dry Florida conditions. In general, leucaena's northern production limit is said to be defined by the dashed line in Figure 2.1.

FIG. 2.1

Estimated leucaena growing zones for the southern U.S.



2.2 Rainfall: *Leucaena* grows best where annual rainfall is 1,000 – 1,650 mm (39–65 in). However, it can survive in dry areas with average rainfall of 635 – 762 mm (25–30 in) (Brewbaker, 1980). The common type (Hawaiian) is the dominant vegetation on Honolulu's Diamond Head where annual rainfall is only 250 mm (10 in) (NAS, 1984). In Israel, *leucaena* has been grown in pits in the Nagev (or Ngev?) Desert to accumulate the sparse moisture during the two month rainy season. The roots are underwater for this time (). It can grow well over a wide range of rainfall provided soil drainage and nutrient requirements as described above are satisfactory.

2.3 Temperature and Light: Following the danger of permanently water-logged soils, the next biggest problem for successful *leucaena* establishment is severe and prolonged low temperatures. Young plants have been killed by freezes in South Florida (Rockwood, 1994). Eighty percent of K8 rootstock has survived and resprouted following temperatures in Texas as low as -12°C (10°F) with 169 hours below freezing. All plants survived temperatures of -9°C (15.8°F) in the same location (Glumac, 1986). McCarty giant and a common type in a north Florida (Branford) nursery, two years old at the time, survived the freezes of 1983 and 1984 (Cunilio, 1991). Numerous giant selections in an accession nursery planted in 1979 in Gainesville, FL have survived the hard freezes of 1983, 1984 and 1989 (Cunilio and Prine, 1991). Few *leucaenas*, however, are regarded as highly frost tolerant (Gutteridge and Sorenson, 1992). It takes several hours of temperatures below 30°F (hard freeze) to kill the plant to the ground. If this happens and the ground does not freeze, regrowth will occur from the basal crown as a multibranched shrub. Generally, when new plants have been growing vigorously for 3–6 months or more, there is little likelihood that a winter freeze will entirely prevent regrowth the following year (Cunilio, personal communication).

Generally, *leucaena* grows best in full sun and under high light intensities. Optimum temperatures for *leucaena* appear to occur in the $25\text{--}30^{\circ}\text{C}$ ($77\text{--}86^{\circ}\text{F}$) range. Growth rates presumably relate directly to temperature. Suppressed or shaded trees are slow to die and often persist for years with very little growth until the canopy is opened (NAS, 1984).

2.4 Weed Control: Probably the major cause of failure or slow establishment of *leucaena* in the first year is competition for light and water by weeds. This includes grass which has not been totally killed for no-till purposes. Weed control is essential for reliable results. Regular weeding until plants are 1–2 m tall gives best results (NAS, 1984). On large areas the use of herbicides is an option. So far, no entirely satisfactory herbicide for all soil situations in Florida is available. Chapter 5 discusses experiences in the USA and other countries in greater length.

2.5 Insects, Diseases and Pests: The most serious insect pest in Florida and worldwide to date has been the nymph of the psyllid (*Heteropsylla cubana* Crawford), a defoliating, jumping plant lice which have attacked *leucaena* all over the world from late 1982 to the present. *Leucaena* psyllids are tiny insects (1–2 mm) of the Homoptera family. Eggs are yellow, found primarily on young, terminal leaves and hatch in 2–3 days. Nymphs, which resemble aphids, undergo five instars over eight to nine days. Adults are larger than the largest nymphal instar. Their reported color has ranged from green to brown to whitish. They have stout legs used to jump before taking flight when disturbed. Females begin laying eggs 1 to 3 days after becoming adults. Psyllid damage is greatest when juvenile foliage is growing rapidly as in hedges managed

for green manure and or fodder. Leaflets turn yellow, curl and wilt (Brewbaker, 1988).

In Florida an infestation occurred in 1984 and 1985 resulting in the defoliation of young leaves of many, but not all varieties and species in Gainesville and Brooksville. This outbreak led to a worldwide psyllid resistance trial (Austin et al., 1990). The psyllid populations are drastically reduced by the cold weather each year and has not been serious problem since (Othman, 1984). Outbreaks are inevitable especially in rapidly coppicing plants following harvest for wood. For this reason, the leucocephalas which have shown psyllid tolerance as young trees should be mixed (Brewbaker, 1988). (See Chapter 3.) Stink bugs will attack green pods and have reduced seed yield by 5% in Central Florida (Cunilio, 1993).

Leaf-cutting ants, deer, rabbits and other wildlife have been known to damage leucaena (van den Beldt, 1985). The larva of the moth *Ilthome lassula* which feeds on flower heads, has been reported in Florida (Bullock, 1989). The critical stage, however, is during the establishment year when great caution must be taken to keep predation to a minimum. There have been no serious diseases of leucaena observed in Florida and only two diseases reported from overseas which have not yet caused serious consequences, a fungal gummosis (*Fusarium semitectum*) and a leafspot fungus *Camptomeris leucaenae* (NAS, 1984).

CHAPTER 3 CULTIVARS, BREEDING AND SEED

- 3.1 Cultivars: The many leucaena cultivars can be divided into 3 main types:
- Giant: tall and sparsely branched, good wood production (to 30 - 40 ft. in height);
 - Common: short and bushy (5 - 8 ft. in height);
 - Peru: multibranched, leafy, medium height (15 - 24 ft.).

The leucaenas which have proved superior in wood yields in Florida are mainly of the giant type. Some outstanding and widely used giants are K8, K636, K28, K29 and K67 (van den Beldt, 1985). Following 15 years of research in a world collection nursery in Gainesville, FL, 25 accessions have been identified for vigor and persistence. All are leucocephalas (Cunilio, ????, unpub. data). A small number of *L. pulverulenta*, *L. restusa*, *L. lanceolata* and *L. diversifolia* accessions from the same collection resemble giant types in height and/or vigor. Work continues to identify accessions with desirable characters such as low seededness, psyllid and cold tolerance in Florida, Texas and Hawaii (Brewbaker, 1994; Cunilio, 1994; Glumac, 1986). The variety "McCarty giant" with no "K" designation as yet, has been investigated for wood production and frost tolerance; it is a *leucocephala* (Felker et al., 1986). The use of the letter "K", developed by James Brewbaker of the University of Hawaii, refers to the Hawaiian word for leucaena, Koa, and is followed by a 1 to 3 digit number. Most "K" numbered leucaenas refer to distinct leucaenas collected in the wild and initially given a six digit accession or PI (plant introduction) number by plant explorers (Brewbaker, personal communication).

3.2 Breeding: All of the leucocephalas are self-compatible and highly inbred. Early breeding efforts in the 1960's concentrated on locating variability in *L. leucocephala* but due to a growing recognition of the narrow genetic base of this species, recent efforts have concentrated on infusing genes from the lesser-known species. Such hybrids may ultimately be used to expand the range of leucaena to colder and more acidic sites. It should be noted, however, that seed from such hybrids will probably not be marketed for a few more years (van den Beldt, 1985). It is now clear that crossing different leucocephalas often yield superior genotypes owing to heterosis (Brewbaker, 1993).

There have been numerous psyllid resistance trials worldwide following the outbreak in the 1980's. At Brooksville and Gainesville, varieties were identified which seemed to possess some tolerance or resistance to the psyllid. Of these, K651 (a giant type) and K584 may be suitable for biomass and/or forage.

Also in Florida, *L. pallida* and *L. esculenta* have shown the highest psyllid tolerance under fodder management followed by two hybrids: KX1 and KX2. Eight species of parasitic arthropods were found in the Florida psyllid trial (Austin, 1990). In general, it is recommended to plant a mixture of varieties to more efficiently spread the risk of pest infestations (Brewbaker, 1988; Williams, 1993).

Mark Hutton, in Brazil and Columbia, hybridized leucaenas using accessions which demonstrated natural tolerance to high levels of aluminum and soil acidity. Some of this seed is being evaluated and increased in Florida (Soffes, 1984). It is recommended that interested

producers consider obtaining enough seed to begin a seed orchard or a minimum amount to put into small plot trials to determine specific site adaptability. Where large scale production

of leucaena is planned, such pilot trials and soil analysis are strongly recommended. (See Chapter 4 for a discussion of nursery management.)

3.3 Seed Scarification: For direct planting, a high quality seed with a germination percentage of 75% or greater is desirable with leucaena (Kang, 1994). Germinating leucaena seed absorb water through a seed coat structure called the pleurogram which is tightly closed in mature leucaena seeds (Olivera et al., 1982). In nature this usually results in germination over a long period of time. In order to promote germination, the pleurogram must be cracked (scarified) to permit the entry of water and thus hasten germination. Kang (1994) and van den Beldt (1985) have recommended three major methods of scarification:

1) Hot Water Scarification: There are two hot water scarification methods for leucaena: one for small lots of seed and the other for larger seed quantities. Both methods result in the opening of the pleurogram. It is the simplest method for treating small and large quantities of seed. However it can give erratic results if not done properly. For small quantities of seed (a few ounces to 2 to 3 pounds) water is heated in a large container to 80°C (176°F). The seed is immersed into the water and kept there for 3 to 4 minutes with constant stirring. The seed is removed, immediately cooled with water and sun or air dried before planting. With the second hot water method, the bag of seed is immersed into boiling water and kept there for four seconds, removed and immediately cooled in cool water. The seed/water ratio should be 1:3 by volume and the minimum water volume should not be less than one liter. Seeds scarified in either way can be held in a cool dry storage area for up to 6 months (van den Beldt, 1985). Another alternative for storing such seed is to freeze the seed after thorough drying (Kalmbacher, personal communication).

2) Mechanical Scarification is accomplished by rubbing seeds against an abrasive surface such as sand paper or mutilation of part of the seed coat. Care should be taken not to damage the seed embryo.

3) Chemical Scarification: This method results in micropores being produced over the entire seed coat thus allowing the imbibition of water. This acid treatment gives consistent and reliable results, though more costly and dangerous than hot or boiling water treatment. Seeds are treated for 30 minutes with concentrated (commercial grade, 98%) sulfuric acid using a seed to acid ratio of 10:1 by volume. During treatment, seeds are occasionally stirred. Following treatment, seeds are rinsed with water to remove traces of acids followed by air or sun drying (Kang, 1994).

TABLE 3.1. Comparison of scarification methods for leucaena (van den Beldt, 1985).

	80°C Water for 3-5 min	H ₂ SO ₄ for 30 min	Hand scarified	No treatment
Percent germination after 2 weeks	90%	95%	95%	10%
Expense	low	medium	high	—
Storage capability (dried)	6-12 mo	6-12 mo	6-12 mo	1-5 yrs
Safety risk	medium	high	low	—
Germination time	4-7 days	4-7 days	4-7 days	4-60 days
Ease of operation	medium	difficult	simple	—

3.4 Seed Storage: Dry leucaena seed store well for many years. It appears they can be kept indefinitely under dry (30% relative humidity) and cool conditions (Cunilio, ????, unpub. data). Scarification reduces the storage life of the seeds if kept at ambient temperatures. Freezing scarified seed is recommended but seeds that are hot-water scarified followed by drying may be stored for as much as a year. Acid scarified seed should be planted immediately after scarification. It is generally best, however, to sow seed immediately after scarification to avoid any viability loss in storage (van den Beldt, 1985). Although differences in storage viability loss have been noted among the leucaenas, it is not yet known if these differences relate to genetic or environmental factors (Cunilio, personal communication).

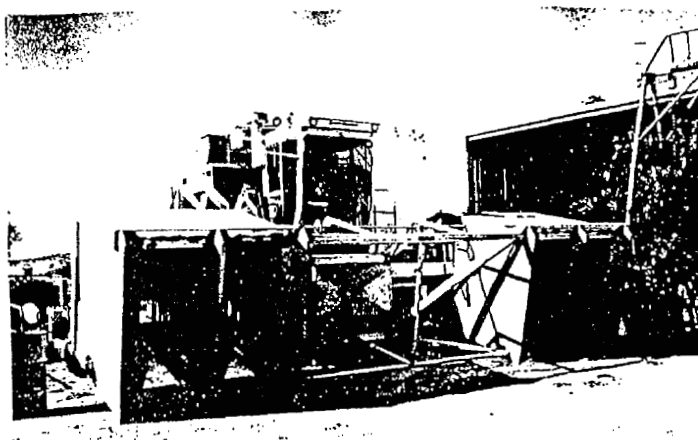
3.5 Seed Production: Producing leucaena seed is relatively simple compared to many tree species (van den Beldt, 1985). Only the common or bushy types are referred to as potential pests because of their large number of seed (Watson, 1994). The giant and Peru types have not become weedy at nursery sites in Central and North Florida nor in any other part of the world (Cunilio, 1994; Brewbaker, 1980). In Florida, good seed yield in the second and subsequent years of growth is possible from well established plants. Seed production is not, however, guaranteed due to the possibility of early frosts before pods mature (Prine, 1993). If seed is going to be produced the following must be borne in mind:

- obtain good seed or seedlings from a reputable source.
- plant seed or seedlings at a spacing of 1 X 2 meters or in double hedgerows with 15 - 30 ft. of open (grass) alley on each side.
- if more than one variety is being planted and purity is a concern, do not

- plant within 300 ft.
- thin after 1 – 2 years to 2 m in the hedgerow removing any off-type plants carefully at this time.
- cut trees to a stump height of 3 ft. at the time of maximum seed yield and remove the pods (van den Beldt, 1985; Brewbaker, 1980).

Based on work by the Hawaiian Sugar Producers, seed production of K636 will range from ¼lb to 4½ lbs per tree depending upon spacing. In narrow row spacing, seed production is usually reduced. Insect damage has reduced yields by 50% in Hawaii. Seed is collected when pods are completely brown and should be harvested before opening. Harvesting is almost always done by hand using tree pruners, cloth bags, driers, and shellers. The mechanical harvesting of *leucaena* is being developed in Australia (Dudley, personal communication). Combine harvesting has been employed in Australia on the cultivar Cunningham (Fig. 3.5.1). With a combine harvester, the trees are kept short via yearly stump cutting thus facilitating the combine head to reach a majority of the seed.

Fig. 3.5.1
Gleaner combine head designed for *Leucaena*
(Larsen, 1994)



Gravimetric cleaners have been successfully employed to separate whole, heavy seed from damaged and light seed (Cunilio, 1994). In general, the size of any seed orchard will be determined by the production goals and the constraints imposed by the environment, labor availability, and machinery. (Chapter 4: Nursery Management)

Giant *leucaenas* produce their sparse seed mainly high in the canopy. In hedgerows especially, heavy, seed-bearing stems will bend thus making hand harvest practical. *Leucaena* is not photoperiodic and is indeterminate. This means that seed will be produced at least twice during the growing season though, heaviest flowering begins in late spring in North- and Central-Florida on mature (3 yrs and older) plants and continues through the summer. Flowering also takes place if the plant is drought stressed (Cunilio, personal communication).

Seed is produced in Hawaii by withholding irrigation during part of the long, dry season to keep the already pruned plants short then by forcing them with water before the cool, rainy season when production slows (Dudley, personal communication). In Florida, the only commercial seed orchard at the St. Leo Abbey produces clean seed by keeping plants irrigated throughout the normally dry spring and harvesting during early summer (Br. Felix, O.S.B., 1993). Presently, seed production in Florida is by hand labor and quantities are limited. Seed availability in Australia is constrained by present demand in that country. On a recent trip to Brazil, the junior author found seed of some leucaena cultivars could be bought there for less than \$10 a pound.

CHAPTER 4 NURSERY MANAGEMENT

4.1 Seedling Production Requirements (Option 1): Giant leucaena varieties can be established directly from sown seeds or from transplanted seedlings grown to the age of 3 to 4 months. Transplants are to be considered more rapid and reliable but also more costly. Given the present high cost of good, giant-type seed (\$30 to \$80/lb), it is perhaps essential to discuss both options from the point of view of inputs needed. This discussion comes mainly from the Molokai Study Team's "Giant Leucaena Energy Tree Farm" and is referenced in the bibliography of this guide (Brewbaker, 1980).

Assuming an energy tree farm of 1,000 acres to be planted at a density of 4150 seedlings/acre (10,250/ha) over a 4-year period (250 acres/yr) and allowing for some loss (13%), about 1.2 million seedlings are necessary. The 1.2 million seedlings would be produced as three crops of 400,000 at 4-month interval. Using a dibble tube system in styrofoam racks at a density of about 40 tubes/ft.², a nursery facility of about 1.5 acres would be necessary. The seedling culture area would be about 0.25 acre in size and covered with about four inches of crushed rock. An irrigation system, a shade system to protect seedlings, cement blocks supporting pallets of processed racks and tubes, and an office would represent major inputs. Estimated capital costs would depend greatly on current prices but were calculated at \$158,000 total by the Molokai Study Team in 1980. Total annual costs of labor and materials was calculated to be \$75,000. A complete materials list is available from the corresponding author of this guide.

Establishment of a seed farm to produce at least 250 lbs. of leucaena seed annually is considered economically feasible for the 1000 acre plantation. Seeds of superior giant leucaena cultivars are limited in supply. The seed farm should consist of at least 1000 plants on a 3x6 ft spacing. About 0.5 acre would be required. Total seed value at current seed price of \$45/lb would thus be \$28,125 assuming need for five million seed. The actual cost per pound should be substantially less if plantation seed is grown by the producer.

4.2 Direct Seeding (Option 2): Direct seeding is presented as a major alternative to nursery construction and transplanting of leucaena seedlings. Direct seeding is less expensive but requires better land and land preparation. Capital investment is reduced for the nursery itself and for transplant equipment and labor. Direct seeding could be done in a much shorter time frame. Major disadvantages of direct seeding include the risks of excessive weed growth and inadequate or excessive leucaena stands. It may be necessary to thin or perhaps reseed to effect desired spacing.

It is estimated that scarified leucaena seeds will germinate 80% and that more than 50% field loss would be sustained. At least 5 lbs of seeds per acre should be used to obtain the desired population (4150/acre). Assuming 5 lbs of seeds per acre (8,000 seeds/lb) the plantation will require 5,000 lbs of seeds (vs 625 lbs for nursery plantation method). The added seed costs \$225,000 at \$45/lb. As noted above, this cost might be reduced substantially by seed produced directly on the plantation itself or by importing.

Good agronomic practices, weed control and thinning are to be counted as necessary for direct seeding of leucaena. Increased costs from these methods over that required for

transplanting are estimated by the Molakai Team at \$62/acre. However, it is pointed out that low-till or no-till methods are advisable if possible with herbicide Roundup and tillage only of narrow bands for seeding. Such a planting system has been attempted in Florida by the USDA in 1994 at Brooksville using a bahiagrass pasture. Planting was carried out with a John Deere Maxi-Merge Planter (Valencia, 1994). The results are inconclusive, however, since dry weather following planting in early summer resulted in the loss of a large percentage of the seedlings. Hard seed found 2 months after planting may also have contributed to the problem (Cunilio, 1994). No-till planting, however, still seems to be a practical method to establish leucaena for wood and other uses.

CHAPTER 5

FIELD PREPARATION AND PLANTING

5.1 Soil Testing and Fertilization: Soil fertility and pH of phosphatic clay soil may vary somewhat from location to location. Therefore a soil test is recommended before establishing leucaena. The pH of phosphatic clay varies from approximately 7.0 to 8.0 which is ideal for leucaena production. Phosphatic clays are well buffered so the pH remains stable for many years. Although good for general nutrient uptake this high pH may reduce the plant's capacity to absorb micronutrients such as boron, copper, manganese and zinc. Phosphatic clays are rich in phosphorous, calcium and magnesium with adequate amounts of potassium. This high fertility also makes the clay suitable for leucaena production (Shibles et al., 1994). Supplemental nitrogen is generally not needed for leucaena production since the plant is a nitrogen fixer. But where high populations of leucaena are used for cut forage or wood grass, supplemental nitrogen is recommended (Jayaraman et al., 1988). (Section 5.5) Because leucaena is a legume with a strong taproot when grown on deep soils, in-row fertilization will supply nutrients most effectively especially in the establishment year. As the age of the stand increases, broadcasting fertilizer over the field will assist the later developing secondary side roots (Cunilio, personal communication).

A University of Florida soil test recommendation for leucaena has not yet been established. But as potassium is likely to be the limiting nutrient on mineral and phosphatic clay soils during the first 4-6 years, a minimum target soil K_2O concentration of 30 ppm is recommended. Most mineral soils in Florida will require 300 lbs/acre of complex fertilizer of 0-10-20 NPK with micronutrients where pH is 6.0 or above. Where the soil pH is less than 6.0, calcium deficiency may be a major limiting factor to leucaena growth. Dolomitic limestone at 2000 lb/acre can be added to supply sufficient Ca and Mg (van den Beldt, 1985).

Another important issue affecting leucaena is the subsoil pH. Because there is no commercially produced varieties for strongly acid soils attention must not only be given to the tillage layer but to the subsoil pH. An important source of information is the soil survey. If the soil survey describes a soil as having very little clay in the 2 m horizon, the lower limit for subsoil pH is about 4.7. If there is considerable clay in the lower soil and the pH is low, then exchangeable Al is likely to be high which will result in toxicity to most leucaena varieties (Kidder, 1994). Liming can correct this subsoil acidity. There is likely to be, however, a greater problem with a high water table (within 1 meter or 3 feet) in which case special site preparation or time of planting is needed. (Section 5.3.c)

5.2 Season of planting: The time of planting can be critical for the establishment of leucaena particularly in the seasonally dry peninsular Florida with its bimodal dry seasons (Spring and Fall) and pronounced cool season (Winter). Nearly all relevant experience with leucaena in Florida has concentrated planting during the rainy months of June, July and, in south Florida, August. Severe dry weather will kill newly planted seedlings. Direct seeded plantings are even more sensitive to early rains than are transplanted seedlings (van den Beldt, 1985). The only exception to the above is on the phosphatic clays of Central Florida and flat woods sites where light irrigation will keep the seed bed from excessive drying in the Spring. In these cases planting as early as March and April has been possible following dry season

tillage. In general, leucaena needs from 3 to 4 months of high temperatures, adequate moisture, weed-free environment, and fertile soil to reach a height (approximately 3 - 4 ft) which will allow it to recover from any hard freeze which may attempt to claim it in its first year. Following a successful establishment year, leucaena in Florida should be able to survive indefinitely (Prine, 1993). A ten-year life for leucaena stands should be used in planning for the crop on soil favorable to the crop.

5.3 Site Preparation: Site preparation methods for leucaena vary depending on intended use, type of planting materials, topography and vegetation of the area to be planted. Site preparation is very important to the success of establishment as poor soil fertility and weed growth can easily defeat the establishment of young seedlings (van den Beldt, 1985). The good manager is advised to keep in mind that leucaena is a long duration perennial whose cost to establish can be spread over the expected 10 year life span of the stand.

Begin with a thorough knowledge of the soil using: 1) the soil survey especially for subsurface soil characteristics and 2) careful soil sampling and thorough lab analysis. Because leucaena usually becomes a deeply rooted perennial tree/shrub, attention must be given to both tillage layer and subsoil pH as stated in Section 5.1.

In general and following a thorough understanding of the soil factors, the site should be well cleared, disk plowed, then bottom plowed 4 to 6 months before planting and levelled with lighter disking. The following site variations are given separate consideration below.

5.3.a Settling Ponds: Phosphatic clay in settling ponds is a man-made soil and is unique to Florida where natural soils are typically sandy or organic in nature. Phosphatic clays have high fertility and water holding capacity reducing the need for significant irrigation and fertilization. Efficient production on phosphatic clays have low energy input requirements (Stricker et al., 1993).

Phosphatic clay ponds typically occupy about 50% of the mined sites and normally require 10 to 15 years before 40 to 50% solids are obtained. These clays contain no phytotoxic materials. When surface water has disappeared these clays are classified as clayey Haplaquents (Zellers and Williams, 1978).

Preparation of phosphatic clay sites for leucaena production should begin as early as possible. Allow at least 4 to 6 weeks for soil preparation before planting in the spring. Soil should be reasonably level, ditched and free of all weeds at planting if direct seeding is contemplated (5.3.b). Leucaena should be planted in microbeds which allow rapid removal of surface water and no depressions in field to collect surface water for long periods of time. Preparations for both mechanical and chemical weed control should be made. Timely mechanical cultivation may consist of primary tillage with disk plow and/or moldboard plowing in the fall or early winter followed by secondary tillage with a power tiller or disk harrow. Rain events occurring between tillage operations will help break up clods and hasten development of a firm, level seed bed. It may be necessary to spot treat bermudagrass with one or more applications of grass killing herbicide. Bermudagrass will not easily be controlled with tillage alone. A combination of herbicide and light disking may also be an effective method of preparing the soil in the spring (Stricker et al., 1993). Ideal tillage conditions are reached 3 or 4 good drying days after plowing/disking/tilling or a rain event. If the field is reentered without

sufficient drying, the tractor may leave deep depressions in the clay and/or the clods will not shear adequately (Shibles et al., 1994). If a good stand of any low growing grass is on the site, the recommendation for "grassland planting" which follows may be appropriate. In general, however, for the phosphatic clay sites and for other farm land, a thorough tillage generally results in fewer weed problems and better root penetration after planting.

5.3.b Grasslands: Many leucaena plantings outside of the phosphatic clay settling pond sites are likely to involve seasonally well drained, open pasture land and palmetto prairie covered with coarse, perennial grasses both native and improved. If leucaena is to be grown here for biomass, then either conventional seed bed preparation or no-till planting can be considered. With conventionally prepared sites where herbicides are not a viable alternative, the seed bed must be well prepared indeed.

Minimum-till or no-till planting has been contemplated for leucaena and recently tested (Williams, 1993). The principal rules of thumb to consider with any minimum tillage planting are total in-row kill of vegetation with herbicide, depth of placement of seed, calibration of planter and seed rate and additional weed control. Weeds compete for moisture and light and must be controlled especially in well drained conditions. Leucaena for biomass/wood planted in this way especially could be economical. A further discussion of leucaena for forage can be found in Sections 5.3.c and 5.6.

5.3.c Flat Woods and Seasonally Wet Sites: Site preparation for leucaena where the water table is within 1 m (3 ft) of the surface during the rainy season requires a special approach and really has a practical application: hedgerow-based cattle systems. Leucaena establishment conditions require dry season planting, i.e. March to May. Following establishment, the plant will tolerate seasonally wet conditions including standing water which many Florida sites exhibit (Cunilio, personal communication). Kalmbacher achieved the needed well drained seed bed at Ona by using a two or four bottom plow to throw up a ridge or bed from both directions in the field leaving 15 to 45 feet of grass alley. Initially, the ridge does not have to be more than about 6 inches high (Kalmbacher, 1990). (Note: it can be generally assumed that a growing 500 pound heifer will require 0.9 lb. of crude protein per day and that a 1 acre paddock with 33% leucaena in bahiagrass, will result in an animal gain of 1 lb/day/animal [Kalmbacher, 1993]). One to three rows of leucaena will be planted on the ridge; it is practical to continue the seed bed preparation with light equipment disking or roto-tilling before fertilizing and planting.

5.4 Herbicides: It must be said at the outset of this discussion that presently there are no herbicides labelled for leucaena in Florida. All references made here must be understood to refer to purely experimental study.

After site and seed-bed preparation, should come the application of a preemergence herbicide. At present, no one herbicide has been shown to suppress both grass and broadleaf weeds in leucaena, a situation mainly due to the relative newness of the crop in Florida. There has been limited experience with herbicides in general even where leucaena is grown extensively. However the general principle of "knowing your weeds" should be followed which means that for preplant and preemergence applications the weed problem must be anticipated since weeds may not have emerged at the time of application. This can best be done by observing the field in

the fall and, recording the weeds present and their location in the field (Colvin and Brecke, 1993). Once the weed problem has been determined, Table 5.1 may be helpful in determining which herbicide should be used.

TABLE 5.1. Preemergence Herbicides Used in Leucaena Establishment.
(Experimental only)

Trade	Name Common	Weeds Controlled	Rate lb. a.i. per acre	Control	Reference
Sencore	metribuzin	brdlf	0.25-0.38	6 wk	Williams, 1988
Lexone	metribuzin	brdlf	0.25-0.38	6 wk	Williams, 1988
Alanap	naptalam	grass	5.0	8 wk	Kinch, 1962
Solicam (Zorial)	norflurazon*	grass brdlf	2-4	12 wk	Felker, 1986
Nitrofen	?	?	4	?	Olivera, 1982
Surflan+Orizalin		brdlf grass	4+2	?	Olivera, 1982
Treflan	trifluralin	grass brdlf	0.5	?	Ramon, 1994

* Solicam was reported to give excellent control of both broadleaf and grasses on sandy and clay soil in west Texas under dry conditions and has given the best control in 12 wks in experimental work at St. Leo, FL. Hairy indigo in one part of the field was, however, not controlled (Cunilio, 1994).

Note: Australian investigators have successfully established leucaena on grasslands by covering drilled seed with a 1-inch band of slurried, activated charcoal (cost: 15\$/acre), conferring protection against high herbicide levels. This is followed by band application of 8 lb Dacthal and 6 lb 2,4-D per acre. Weed competition was virtually eliminated with this method, common also in the U.S. turf seed industry (Brewbaker, 1980).

With leucaena, failure to control weeds during establishment can result in total stand failure (Williams, 1993). If planted correctly, the seedling will emerge in 4 to 7 days and should be ahead of the weeds at this point. Slow initial leucaena growth, even under ideal conditions, should be expected however. In 1994, leucaena planted at an Osceola County ranch with no herbicide experienced strong competition from hairy indigo after successful emergence. The indigo was topped with a rotary mower to get light to the seedlings (Kalmbacher, personal

communication). To keep establishment cost low, it is this guide's recommendation then, that for hedgerows with 1 to 4 widely spaced rows (36 inches or wider) of leucaena, the preplant or preemergence herbicide can be directed over the row by spraying a 10 to 18 inch wide band on the bare ground. The same applies to a no-till planting using glyphosate. The importance of lightly tilling or watering in the herbicide should not be forgotten. Mechanical weed control using, for example, a rotary hoe, could assist seedlings after the eight week stage. The herbicides available for post-emergence use are described in the next Chapter.

5.5 Direct Seeding: Because quality leucaena seed of several varieties is now being produced in Florida, direct seeding as opposed to using transplants is to be recommended for most applications. (It should be mentioned again, however, that seed orchards can be established using seedlings.) Leucaena has been seeded in different parts of the world through one of the following three ways: 1) broadcast, 2) conventionally with grain drills and, 3) most recently using a no-till planter. No matter what method is chosen the critical factor is depth of seed placement (Kang, 1994; Williams, 1993; Prine, 1993; Kalmbacher, personal communication). Leucaena seed will have great difficulty emerging if sown more than 0.75 inch depth from the surface; and, on the phosphatic clays this is reduced to 0.5 inch of soil. Given the fact that the plant is going to be productive for many years it is worth the effort to calibrate and recalibrate the planting equipment and check and recheck the planting depth.

Broadcasting seed cannot be recommended unless the variety is small seeded like the variety in use at Ona and light harrowing or disking followed by cloudy, rainy weather. This is a method used in Indonesia and the Philippines from the ground and the air to reforest steep slopes (NAS, 1984). It may be practical only for rangeland and cattle production and not for biomass plantations. Scarified seed should be sown at 2-3 times the normal rate (van den Beldt).

The choice of planting equipment to direct seed leucaena will depend on many factors the main one being the purpose for which it is being grown and the harvesting equipment to be used. In Florida, leucaena has been planted by hand with two and three row corn planters and most recently with a no-till planter. Any planter or system properly calibrated can be used to plant leucaena. An important question recently raised is whether, for biomass, planter plates should be used to drop 2 to 3 seed per hill or whether drilling the seed continuously over the row should be preferred. As stated in Chapter 4, high quality leucaena seed germinates at 80% but 50% and higher field losses should be expected. The Australians, in fact, say that one should expect only a 10% to 30% post-emergence survival but this is under the dryer conditions of south Queensland (Partridge, 1989). The low survival rate through direct seeding is one of the reasons why transplanting seedlings is suggested. The literature and references to date have spoken of using only grain drills to direct seed leucaena. In either case, thinning will more than likely be necessary to reduce plant population to the recommended 4150 plants/acre.

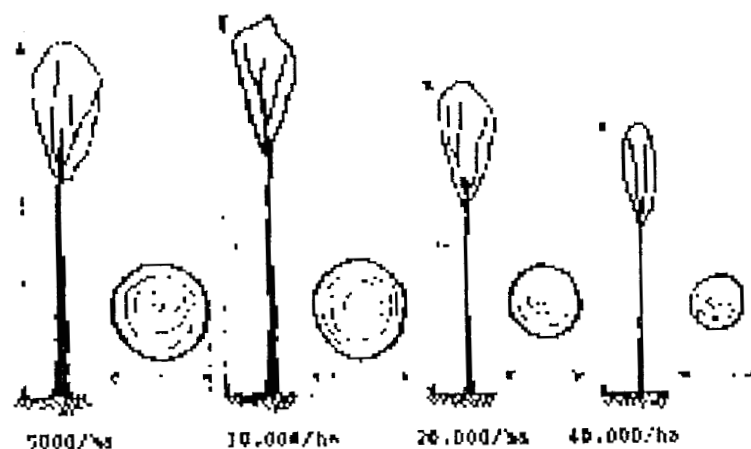
5.6 Spacing: The diameter and height development of leucaena is influenced by the per acre populations. Generally, diameter growth is affected more, because of dense population, than the height growth. Thus spacing is an effective management tool which, when considered in conjunction with rotation age, can be used to produce material of suitable diameter and length for many different purposes (van den Beldt, 1985) (Fig. 5.1). The key to using spacing as a

management tool is to keep in mind four major determinants:

- The use intended for the product: If small diameter material is desired, closer spacing is indicated. Large diameter trees require more growing space.
- Site quality: On weedy sites or where herbicides are not used it may be necessary to opt for closer spacings to shorten the time of canopy closure.
- The age at which a particular spacing will inhibit growth: Different spacings give optimum per acre volumes at particular ages. The closer the spacing, the less time it takes to complete one rotation (van den Beldt, 1985).
- The machinery which will be used to harvest the material. If stem diameters are 0.75 inch or less, unmodified farm equipment can be used successfully. If stem diameters are greater than 0.75 inch then other equipment must be used (Stuart, 1994) (Chapter 7). In all cases between row spacing should be determined by the width of the equipment to be used in harvest (Prine, 1993).

Figure 5.1

Effects of population density on height and development of 4-year-old leucaena trees. Values are averages of plots in a spacing study conducted at Hawaii (van den Beldt, 1985).



Maximum total wood yield of leucaena without regard to wood quality is achieved by populations densities of between 4,000 and 8,000 plants per acre (10,000–20,000/ha). For fuel wood plantations these populations lead to small diameter trees of somewhat shorter stature but with more total wood per acre than wider spacings (van den Beldt, 1985).

The concept "wood grass" has been used for leucaena populations greater than 16,000 plants per acre (40,000/ha). Here, wood quality is not the goal but it is the leafy biomass. In Taiwan and India a planting geometry of 10 inch wide rows with plants 6 inch drill spacing yielded 22.8 t/A edible fresh weight containing 3420 lbs protein per year over 5–years and four harvests per year (Shih et al., 1989). The cultivar used was K28. This spacing represented a population of 81,000 plants per acre (200,000/ha). Such a farming system would require an inexpensive seed source and a good fertility program. It is not known how long such high population will survive.

5.6 Thinning and Pruning: The practice of thinning to remove off-type and immature trees and reduce plant population is less important than with other tree species since leucaena is a self pollinating plant with little or no difference from plant to plant. Observed differences will be primarily due to microenvironment and to competition at high population densities (van den Beldt, 1985). Wherever two or three seed per hill germinate and plant vigor is good removal of the smallest seedlings may be advisable if labor is available. Two laborers can thin two acres per day (Brewbaker, 1980). Leucaena is highly self pruning at normal densities while some varieties like McCarty Giant will side branch at wide spacing (Raymon, personal communication).

In grazed forage situations it may be necessary to employ an orchard pruner at least once per year unless grazing pressure can keep plants from growing above the animals reach (Chapter 9: Alternative Uses). In much of Florida and the Lower South, winter freezes may kill the top growth to the ground.

CHAPTER 6

MANAGEMENT AND PROTECTION

6.1 Weed Control: Regardless of the preplant and pre-emergence herbicides used to establish leucaena, under conventional and possibly even no-till plantings, weeds will be the main source of failure or of an irregular stand until plants are 3-4 ft. tall. There are presently four herbicides which have been used experimentally over the top of leucaena (their use until they are labelled cannot be recommended):

- bentazon (Basagran)
- norflurazon (Zorial, a.k.a.Solicam)
- naptalam (Alanap)
- fluaziafop (Fusilade)

Bentazon at 0.5 lb/acre controls yellow nutsedge by inhibiting photosynthesis. An overdose of bentazon on leucaena will cause yellowing followed by total necrosis (Williams and Colvin, 1988; Colvin and Stahl, 1993). Norflurazon has been used with encouraging results on both sandy and clayey soils at Texas A&M as an over the top where the bare soil can be reached by the spray. Four pounds per acre will give pre-emergence control on grasses and broadleaf weeds for up to a year (100) (Felker et al., 1986). Damage symptoms are unique leaving plants bleached out white (101) (Colvin and Stahl, 1993). Fluazifop for grass control did not harm leucaena at 2 quarts/acre. A post-directed application of these two materials is thus recommended to apply at the base of the seedlings at 6 to 8 weeks. Bentazon and Fluazifop can be tank mixed. Naptalam at 3 lbs a.i. per acre was used successfully in Hawaii with shields to protect the young seedlings (Kinch and Ripperton, 1962).

6.2 Insects and Diseases: In Chapter 2, Section 5, insects, diseases and other pest problems associated with leucaena were briefly addressed. Besides the sap-sucking psyllid (*Heteropsylla cubana*), another potentially serious problem for Florida and biomass production is a leaf spot fungus, *Camptomeris leucaenae*. An outbreak of this disease could lead to defoliation that can be serious on wet sites and which can affect wood increments in bad years. No control measures are reported (van den Beldt, 1985).

The collective wisdom of those working with leucaena is that disease attack and pest predation can be minimized if the monoculturing of only one cultivar or accession is avoided. Since differences in growth (and regrowth) among the giant leucaenas types is not great, the mixing of varieties is strongly recommended for either forage, fuel or green manure (Williams, 1993; Brewbaker, 1988; Prine, 1992).

Seed production is another matter. Weevils and stinkbugs will attack pods and seed and open infection courts will be created for secondary invasions by bacterial and fungal seed diseases. Systemic insecticides that control weevils and stinkbugs are the only known control.

6.3 Fire and Storm: Leucaena has rather thin bark and is very susceptible to fire. Damage is more severe if grassy weeds are present in the stand or in surrounding areas. Wind-blown grass fires can do the greatest damage although leucaena in full leaf is fairly slow to burn. Slow moving, low intensity fires do less damage, burning out a short distance into the stand. There is little likelihood of a fire burning into a biomass plantation since most undergrowth is

eliminated by the leucaena, thus limiting the amount of fuel for a ground fire. Burned trees normally resprout from the base. Probably the best fire control measure is to plant leucaena with good fertilization and management in order to hasten crown closure and suppress understory vegetation before the fall dry season (van den Beldt, 1985). Leucaena cannot withstand repeated fire damage (NAS, 1984).

Wind damage will be restricted to minor branch breaking and defoliation unless seed is being harvested. Seed loads on many varieties at wide spacing will cause main stems to break if plants are not pruned (Chapter 4). In hurricane-prone Florida, biomass plantations should be avoided on soils with shallow water tables, clay pans or highly acid subsoil (van den Beldt, 1984).

6.4 Irrigation: Leucaena is a hardy, drought tolerant plant which does not usually require irrigation after the initial establishment period but the species does respond well to irrigation during dry weather (van den Beldt, 1985). Under severe drought conditions growth is slowed by a reduction in height and diameter growth and dropping of leaves. A well distributed rainfall of approximately 60 in seems important for maximum yields. Supplemental irrigation, when feasible, may be important in seedling establishment and can mean the difference between success and failure during unexpected dry periods (van den Beldt, 1984). In seed nurseries with overhead irrigation, it may be useful to spray the plants when pods turn dark brown which will delay dehiscence especially during hot, dry weather (Kalmbacher, personal communication).

6.5 Maintenance Fertilization: The need for maintenance fertilization is best assessed on the basis of symptoms in the field. Slow growth and low yields often indicate a need for more phosphate. A general leaf yellowing can be due to sulfur deficiency and the use of calcium sulfate can overcome this. Yellow leaf mottling may indicate zinc deficiency and can be corrected easily corrected by application of zinc sulfate. Death of leaflet margins can indicate potassium deficiency (van den Beldt, 1985).

The only reliable basis for maintenance fertilization is foliar analysis. Leaf samples need to be taken at the height of the growing season from newly matured leaves. For good growth leaves should contain approximately 3.5% N, 0.15% P, 1.5% K, 1.0% Ca, 0.2% Mg, 7 ppm Cu, and 35 ppm Zn on a dry matter basis. If foliar analysis show levels much lower than these, requisite amounts of appropriate fertilizer need to be applied (van den Beldt, 1985).

CHAPTER 7

HARVEST OF LEUCAENA

This chapter will treat the important subject of leucaena harvest from three points of view: the species itself, the wood and energy yield of the plant, and selection of equipment for harvest. The largest single unresolved factor in any SRIC energy plantation has been the efficient harvesting and handling of the various species being used throughout the country including leucaena (Turnbull, 1994). Yet the era when a prospective equipment manufacturer could invest research and development funds in a project in the hope that the product would meet the desires of an undefined market is past. Serious producers of leucaena for energy with an established market for their product(s) are challenged with taking advantage of the numerous permutations surrounding leucaena grown in short rotation, intensive culture plantations--species planting density, cultural intensity and rotation ages--before developing a harvesting methodology for one of several broad categories of permutations. This amounts to shooting at a moving target. The following discussion is taken from Bill Stuart's comments in the Mechanization Conference held at Mobile, Alabama (Stuart, 1994).

7.1 Species characteristics: Leucaena as a species is defined by five critical severance and materials handling parameters: stem form, branch angle, self pruning, specific gravity and differences in coppice or sprouting habit.

Stem form: Stem form, whether deliquescent or excurrent¹, has a strong impact on the design of capture and handling mechanisms. With young, giant leucaenas or leucaenas with multiple coppicing stems, one encounters more an excurrent form with low level, multiple, irregular, co-dominant branching. This is also true for growth which is 2-3 years old except that lower branches will mostly be absent. When rotations are long, excurrent forms tend toward a situation where each plant, above a certain height on the stem, is unique: capture after severance and handling demands a method that both holds the stem or stems and forces them into a standard shape or volume for subsequent processing. The mainly excurrent form of mature leucaena presents branch angles of 45° to 90° which requires more energy and effort to fold, and branches which are more likely to break and resist compaction. Downward sloping branches are the most difficult to work with since they resist handling by the butt in larger stems. In the upper canopy of 1 m x 1 m spaced leucaena there will be many downward sloping and small diameter branches.

Branch angle: Varieties with branches more perpendicular to the stem require more hardware and energy in handling. Small diameter, flexible limbs are easiest to handle provided they can be kept from tangling around shafts and other rotating machine components. Branching habit and rotation age combinations which allow branches from stems in adjoining rows to become entangled are especially troublesome with leucaena; the harvest becomes one continuous tug

¹Deliquescent stems lose themselves by repeated branching and trunk divisions leaving no central axis. This is the form leucaena takes in the upper canopy of mature trees. Many horizontal and downward sloping branches are seen. Excurrent stems continue axial growth to the top of the plant and smaller, lateral branches arise. This is the form found in younger leucaena plants and coppice regrowth. Branch angles are mainly at 45°.

of war. Coppice regrowth side branches are thin and angled at around 45°.

Self-pruning: With leucaena giant types, self-pruning is the rule and because of early canopy closure each year severance devices will not have to deal either with large amounts of grasses, or vines and forbs after the third or fourth year of continuous growth. But coppiced plants of one to two years old will have many side branches which will make in row operator visibility a problem if harvested.

Specific gravity: the specific gravity of leucaena (0.50 to 0.70 based on oven-dry weight in gms/green vol in cubic centimeters) is at the higher end among the SRIC species grown (Brewbaker, 1980). Packing densities (volume of material per unit volume of space) should be excellent in chip form especially.

Coppice regrowth: the strong coppicing characteristic of leucaena is going to challenge the mechanical engineer. Stump sprouts of leucaena increase the stool diameter with each harvest cycle until the row crop characteristic of the plantation becomes one of a field crop. Harvesters in this case will have to be changed accordingly (Section 7.3). Accessions from the Gainesville nursery are being identified which seem to maintain a linearity of stand in the row better than others (Cunilio, personal communication).

7.2 Age of Harvest: There is no fixed rotation age for the harvest of woody stems of leucaena. The tree is harvestable for soft, leafy stems in one to two years on good sites like those of the phosphatic settling ponds. When freezes do not kill plants, height growth will continue for five years and diameter growth for ten years (van den Beldt, 1985). In Chapter 5.6, it was stated that spacing of plants affects diameter and height development and may be used as an effective management tool to alter rotational age as desired. Spacing and age also affects wood properties and quality to some degree (Section 7.7 below).

In newly established stands it is recommended that the first harvest not be made before the second full year of growth; three to five years is preferable. This is because the stump size influences number of shoots which regrow (Pecson and Brewbaker, 1991). Following first harvest, subsequent harvests can be made yearly as long as the original stump is not damaged by harvest equipment.

7.3 Coppice Management: Coppicing in leucaena is equivalent to the ratooning in sugarcane except that with leucaena stand productivity increases with age. Coppicing in following the harvest of plants which are at least one year old. Unirrigated, late planted leucaena which is killed back by frost or mowed in first planting season will not coppice (Cunilio, personal communication). Leucaena should not be seeded after August 1 to prevent winter kill during the first winter. In Hawaii, coppice shoot survival decreased on smaller trees. Total shoot number per acre will increase two to four times with the original density of planting but the number of shoots per stump increases as the stump size increases (Pecson and Brewbaker, 1991). Stump size is a function of age of the tree. Trees planted in Gainesville at 1 m x 1 m and frost-killed every 1 to 4 years have remarkably broad stumps (5-10 inches) which have produced 2 - 20 stems per stump depending on variety two months after harvest (Cunilio, personal communication).

Generally, at lower populations (5000-10000/ha) there will be approximately half the

number of surviving shoots than at double the same population regardless of stump size. Also, with well established trees at low populations (less than 10,000/ha), the higher the stump height to 1 meter the more self-pruning takes place leaving few shoots (???). The above applies to soils with both low and adequate soil moisture.

The permutations of leucaena culture will affect machinery selection and performance. For the phosphatic clay sites it would seem that genetic selection toward low coppice shoot numbers at plant populations ranging close to 16,000/acre (40,000/ha) and/or management of rotation age may permit lighter weight, continuous felling harvesters access in large commercial operations (Pecson and Brewbaker, 1991).

7.4 Wood Yields with Leucaena: On the heavy phosphatic clay soils of Central Florida, uncoppiced leucaena dry matter yield over four years totaled 26 t/ac. An average of 6.5 t/A/yr (14.6 t/ha) (Mislevy et al., 1989). On heavy volcanic soils in Hawaii the same variety (K8) with 38 inches of rainfall (said to be not limiting for growth), 12 month old coppice regrowth from well established trees yielded from 12 to 32 wet tons per acre per year at populations ranging from 2,024 to 16,194 plants/acre (5,000 to 40,000 trees per hectare). Wood moisture content on heavier soils has been as high as 58% making a calculated upper yield of 13.4 tons dry matter (Pecson and Brewbaker, 1991). Indeed, the Molokai Study Team used 13 tons dry matter as the yearly average expected for an energy plantation analysis (Brewbaker, 1980). In Gainesville, FL, wood (stem) yields from 12 leucaena genotypes harvested four times with seasons growth over a period of eleven years (1982-1993) averaged 14.0 tons per acre per year over 10 accessions (Cunilio and Prine, 1991). Average annual dry matter stem growth for 4-year-old trees was 19.8 t/ha or 8.8 tons/A (Prine et al., 1994). Wood harvest in Florida would range from an annual harvest each winter when winter temperatures are cold enough to kill leucaena top growth to as much as every five or more years under mild winters or in warm locations. It is also possible to accumulate 2-year growth by letting new regrowth grow up in 1-year-old frost killed growth. The dead stems will stand up for one season and living and dead stems can be harvested together. These dead stems have similar energy to living stems on a dry weight basis (Ravenswaay, 1989). Yield data may be reported on a volume basis per hectare or acre. A value of 87 cubic meters per hectare per year reported from Hawaii converts to 21.36 tons per acre per year. The conversions requires using a specific gravity of 0.55 grams per cubic centimeter and is:

$$87 \text{ m}^3/\text{ha}/\text{yr} \times 0.55 \text{ gm}/\text{cm}^3 = 47.85 \text{ metric tons}/\text{ha}.$$

To convert metric tons per hectare to English tonnes per acre:

$$47.85 \text{ metric tons}/\text{ha} \times 2.24 = 21.36 \text{ tons}/\text{A}/\text{yr}$$

(2.24 is the conversion factor to convert tonnes/ha to tons/acre)

7.5 Mechanization of Harvest: For a plant like leucaena which will, in short rotation intensive culture plantations, form from 10,000 to 36,000 stems per acre averaging 2 to 3 inches with possible root sprouting creating 1-2 ft-wide stools, there does not yet exist an efficient harvesting system. This statement can be made for most if not all of the species being studied for energy plantations in this country. The development of harvesting equipment has been slow, faltering and expensive for a variety of reasons. Many of the historical impediments are still in place and frustrating current development efforts (Stuart, 1994).

Leucaena is unique, however, in that as a nitrogen fixing legume its leaves and smaller stems are known to be a valuable ruminant feed. Any harvesting methodology focusing on leucaena pole wood should take this secondary product into account. The leaf/stem ratio of some newer varieties (hybrids) when full grown are quite high approaching 1:1 from 40-50 t/ha/yr (Austin, personal communication). To this end, Brewbaker has hypothesized whole tree chipping operations utilizing vacuums to extract leaf and twig waste prior to batching. A 13 t/acre dry matter harvest of wood yields 2 t/acre of high quality green leaf meal. Harvesting every fourth year will not adversely affect the nutrient recycling which takes place via deep roots and leaf drop (Brewbaker, 1980).

The optimum tree dbh (diameter at breast height) for mechanical harvesting of leucaena by the Molakai Study Team in Hawaii is visualized as 5 inches (12.7 cm) cut at about 8 inches (20 cm) above ground. Machinery considerations may dictate that alternate spacing be used with 3 ft plant spacing in rows alternately 3 ft and 4 ft apart (about 4,150 stems/acre.) (Brewbaker, 1980).

At four years of age trees should have relatively compact crowns and average 30 ft in height at harvest. Most stems will be vertical except those on exposed edges of the field. The specific gravity of harvested leucaena wood and bark is estimated to average 0.52. Moisture content of these tree parts is expected to average 43% on a wet-weight basis, or 75% on an oven-dry basis. These values significantly influence later calculations of Btu/lb, and are based on limited studies from Hawaii and Florida. Freshly cut wood chips and foliage from above-ground tree portions are estimated to have a bulk density of about 20 lb/ft³ when blown into a bin for transport. Assuming a yield/acre of 13 bone dry tons (BDT) per acre per year and wood with a specific gravity of 0.57, production levels on 250 acres/yr become:

$$\frac{13 \text{ t/acre} \times 4 \text{ yrs.} \times 250 \text{ acres}}{0.57} = 28,000 \text{ green tons}$$

(22,800 tons of wood and 5200 tons of foliage)

For the phosphatic settling ponds of Florida, harvesting 250 acres per year during the drier months of the year (Nov., Dec., Jan., Feb., Mar., Apr and possibly May and June) presents approximately 6 months or 120 working days which translates into the need to harvest 2 acres per day. Such a production schedule would, allowing for 12.5% harvesting loss plus an additional 4% transfer loss, deliver daily to the plant 153.2 tons of green chips from 2 acres (19,152 tons from the 250 acres). The foliage biomass has been estimated to be 10% of the wood weight on an oven-dry basis. The 22,800 tons of fresh wood represent about 13,000 tons of bone-dry wood (13 BDT/A/yr. x 4 yrs x 250 A/yr). Foliage thus will be about 1,300 tons annually (dry weight). Losses are assumed to include 25% in shipping and 25% in small branches and twigs unsuitable for a marketable foliage product, leaving 650 tons of dry foliage annually from the 250 acres.

A critical factor in the choice of a harvesting system is the small size of the harvested tree. With 4,150 trees/acre in this scenario, the average tree weighs but 54 pounds, extremely small by any conventional harvesting standard.

Five harvesting systems can be considered and are briefly described below with some of the more obvious advantages and disadvantages.

1) Bob Tail Truck System. This is a conventional shortwood harvesting method used in the southern U.S. Such a system employs crews of three men, including two chain saw operators and one truck driver/loader operator. The truck is driven to the individual or bunched stacks of wood and is loaded with a boom-mounted grapple. This system is labor intensive with minimum capital investment. It is not designed to handle whole trees. Thus foliage recovery for forage would be precluded. To handle the volume of wood to be harvested per day in this case, it is estimated that at least five crews would be needed which would require a total of 15 men and five trucks. Labor costs alone rule this system out for the Molakai case study.

2) Chain Saw Felling - Manual Bunching. This system requires chipping at the site with a small chipper mounted on a farm tractor pulling a chip wagon. Again, this system is highly labor intensive, but has attractive capital investment characteristics. An advantage over the conventional short wood system is the opportunity to recover foliage for feed since the system is designed for total tree harvesting. During each 8-hour day it would be necessary to fell, bunch, chip and transport the equivalent of 9 trees per minute. Each tree weighs about 50 pounds and would be difficult to handle by hand during the bunching and chipping phases of the operation. Labor costs are considered to be prohibitive in Hawaii for this system but may be affordable in Florida.

3) Feller Bunchers, Grapple Skidders and Roadside Chipper Systems. This system is capital intensive and designed to handle considerably larger volumes per day distributed over fewer but much larger individual trees. When the volume to be harvested is distributed over many small trees per acre, tonnage production rates per hour are very low and the system is quite inefficient. It is concluded that such a system involving several large, extremely expensive pieces of equipment would be over-designed for the task at hand. Furthermore the labor costs would be appreciable since each major piece of equipment needs a skilled operator. This could be an economical alternative if larger trees could be grown in longer rotations.

4) Chain Saw Harvest and Transport of Whole Tress. This option would require transport of small, whole trees to a centralized chipping plant and is believed to be an attractive alternate system. Trees are chain saw felled and bunched, then grapple-loaded on a stake-bodied forwarder designed for rough terrain travel. Trees are reloaded at roadside on a truck with bunk posts rigged to compress the load for road travel and to increase tonnage per load efficiency. A variation of this system might substitute roadside chipping for the bunk-post trucks. The system has the advantage of modest capital investment in specialized equipment. While labor costs are less than the shortwood system, they are still substantial when the entire operation is considered. A more detailed feasibility study of this system may be warranted before actual investments for the harvesting program are made. It has some potential.

5) Swath-Felling Mobile Chipper. The system selected for the Hawaiian Molokai case study in 1980 is probably appropriate for similar situations elsewhere. With this system, a significant advantage is the bare minimum labor requirement which consists of but two full-time persons. The capital investment particularly for the swath-felling mobile chipper is substantial but is also comparable to some other systems considered. The appeal of this system is the fact that it has been designed specifically for harvesting many small stems per acre in chip form which is the requirement of energy plantations everywhere (Brewbaker, 1980).

Since the Molokai Study Team investigated the potential harvesting systems for a

leucaena SRIC energy plantation, the U.S. Forest Service has sponsored the design and evaluation of several farm-scale, tractor-mounted harvesters for small trees (Stokes, 1994). Such equipment is not produced commercially but since much was learned and published, it should be quite possible to bring one or more of the prototypes to Polk County, FL provided that an acreage large enough for testing has been prepared.

If leucaena chips are to be directly combusted for steam generation, the heat of combustion is a major variable affecting tree farm economic values. This production guide does not propose to discuss wood utilization other than to present the relevant (and preliminary) data on heat of combustion of leucaena to allow energy production calculations. This discussion should provide needed information to producers interested in bioenergy from leucaena.

Data from Hawaiian leucaena trees of 9-year-old give as the heat of combustion 8269 Btu/lb for bone-dry K8 wood. Data from several leucaena varieties harvested at four years of age in Gainesville is being prepared at this writing but is not expected to vary greatly from the value of 8269 Btu/lb. This value may be contrasted with the somewhat lower average value of 7827 Btu/lb (bone-dry) for 20 hardwoods of the southern U.S. (Karchesy and Koch, 1979).

Available heat during combustion is directly proportional to moisture content, decreasing linearly as moisture content increases. The value of 51% moisture has been used based on data from bone-dry discs of 13 varieties harvested in January, 1994, after four years growth in Gainesville (Cunilio, personal communication). Assuming combustion at this moisture level, available heat equals:

$$0.51 \times 8269 \text{ Btu/lb} = 4217 \text{ Btu/lb of fresh weight}$$

Since the overall conversion efficiency of conventional steam generation from wood to electricity is on the order of 25% (Benemann, 1978) (if the electric plant is large), the amount of electrical energy produced by burning the fresh leucaena wood chips can be computed as follows:

$$\begin{aligned} 1 \text{ lb of leucaena at 51\% moisture} &= 4217 \text{ Btu; but at 25\% efficiency,} \\ &\text{this 1 lb generates } 4217.3 \times .25 = 1054 \text{ Btu.} \end{aligned}$$

$$\begin{aligned} \text{Since } 1 \text{ kwh} &= 3412 \text{ Btu, } 1 \text{ lb of leucaena} = 1054 \text{ Btu}/3412 \text{ Btu/lb} = \\ &0.3089 \text{ kwh} \end{aligned}$$

$$\text{Therefore, } 1 \text{ ton of leucaena} = 617.8 \text{ kwh.}$$

The total yearly harvest production of the 250 acre plantation was estimated, following losses during harvesting and transfer, at 19,152 tons. The energy equivalency of this harvested wood is:

$$19,152 \times 617.8 \text{ kwh/ton} = 11,832,105 \text{ kwh/yr.}$$

Leucaena under Florida conditions may yield more than 13 bone dry tons per acre per year especially if grown under good management on the phosphatic clay soils of Central Florida. The Hawaiian experience, where a plant population of 4,150/acre is recommended to produce large diameter trees, cannot yet be verified for any site in Florida. The Gainesville nursery was laid out on basically the same plant population basis and thus should be expected to yield useful information regarding total biomass production under long and short harvest cycles. Much has yet to be learned. But good work has preceded the Florida experience from the world over.

CHAPTER 8 ALTERNATIVE USES

Leucaena's utility does not stop with biomass. It has great potential as a forage and green manure or compost for the changing agricultural conditions of the state. The last chapter of this guide discusses one of leucaena's alternative uses.

The situation with leucaena species for wood energy and biofuel production may well involve, as suggested above, many unexpected agronomic and engineering permutations which make successful SRIC plantation enterprises equivalent to shooting at a moving target. But as a forage crop, leucaena production presents a more straight forward challenge. Thanks in large measure to interest in leucaena as a fodder crop at mid century on the part of Australian and Hawaiian investigators and cattle producers, an awareness of the *leucocephalas* began to grow in those countries in which it was already found. Oddly enough those climes had merely the bushy Hawaiian type thanks to the galleon trade during the age of exploration in the 15th through the 18th centuries which transported the abundantly seeded bushy leucaenas from their centers of origin. Since then plant explorers like Al Oaks and James Brewbaker and plant breeders like Mark Hutton and again, Jim Brewbaker, have discovered the giant leucaenas whose study will certainly lead to yet another plateau in the field of fodder (and green manure) production. This development is quite timely since leucaena is still on the 1991 list of Florida's most invasive species (Category II) by the Exotic Pest Plant Council (Watson, 1994). To the extent that any forage species reaches the advanced stage of study by plant breeders and geneticists, as has leucaena, its potential should no longer be ignored. Its success however, is not guaranteed by this fact alone especially in a state like Florida where sustainable agriculture could forever remain undefined and may even connote shades of low input, primitive agricultural practice from the third world where alley cropping, intercropping and no till are originated. In addition, grass-based animal production in Florida has only recently been found willing to look at legume browse genera like *Vigna* and *Stylosanthes*. These conditions may also make leucaena a possible choice for reducing or entirely replacing nitrogen fertilization in South Florida especially.

This chapter will discuss knowledge obtained by investigators working with leucaena as a forage which demonstrates its potential for the Florida livestock industry. It concludes that serious research attention is warranted from animal scientists, agronomists and livestock producers. The discussion will follow A.V. Bogdan's organization in his Tropical Pasture and Fodder Production (Bogdan, 1977). Much of the content here is also from this excellent source now unfortunately out of print.

8.1 Environment: Leucaena is a pantropical, arboreal legume used as a forage almost everywhere it is grown. Although it is best suited to humid and subhumid tropical lowlands with well-drained, nonacidic soils, various leucaena lines are adapted to cooler temperatures of the subtropics or equatorial elevations up to 100 m (325 ft), to areas receiving as little as 300 mm (12 inches) of rainfall annually, and to acid soils with a pH as high as 5.5 (Brewbaker et al., 1985). As early as 1959, Hutton and Gray (1959) stated that leucaena could make a substantial contribution to the protein requirements of cattle on 96 million acres of tropical Australia. In Florida, Othman evaluated 2- and 4-year-old stands of leucaena and concluded that it had

good potential as a forage for seasonally² well-drained soils of peninsular Florida (Othman et al., 1985). Chapter 2 of this guide contains a more thorough discussion of factors which influence the culturing of leucaena.

8.2 Establishment: The best work done to date on the establishment of leucaena for either cattle browse or cut fodder has come from Australia, Brazil and Hawaii. All researchers and producers reiterate the crop's biggest problem: slow establishment. In order to get the seed rapidly germinated the best advice includes the following cultural practices:

- use high quality seed of a known giant variety.
- treat seed by cracking the hard seed coat.
- inoculate seed and sample soil fertility.
- prepare a seedbed and sow the seeds liberally (25-30 seed per meter of row (one seed every 2-5 inches) or 12 lbs of seed per area acre on 1 m centers.
- plant hedgerows leaving 3-12 meters of grass

Good quality seed of the giant leucaenas should be available in Florida by 1995. A small seed nursery of 100 trees widely spaced will provide, by the end of second year, enough seed annually to plant up to 20 acres and is suggested here. The scarification recommended in Chapter 3 of this guide is four second, boiling water treatment. It is not the only one used successfully, however. Inoculum is available commercially. Since only 10-30% of the seed may establish and since even near total germination and survival will result in higher herbage yields from especially widely spaced (10 ft and greater) rows, you will need to plant one seed every 5 cm (2 inches).

Since one pound of McCarty Giant contains approximately 7,300 seed, the following seeding rates can be followed:

- 1.1 lb per acre for a 10 meter (32.8 ft) wide rows
- 2.2 lbs per acre for a 5 m (16.4 ft) wide rows
- 3.6 lbs per acre for a 3 m (9.8 ft) wide rows
- 5.5 lbs per acre for 2 m (6.6 ft) wide rows.
- 12 lbs per acre for 1 m (39 in) wide rows.

The hedgerow system used in Australia and Brazil involves widely spaced rows of at least 3m (10 ft) and varies depending on rainfall and planned use. In humid Matto Grosso state in Brazil a 3 m (10 ft) system is used with a good grass planted the second year between the rows (Raymon, personal communication). The closest spacing cited above is best for cut fodder production. A single hedgerow may contain 1 to 3 or more individual rows. The advantage of planting more than one row is if a fenced-off block of leucaena is being created and more legume forage is needed at a particular time of the year than grass. See Section 8.3 below.

Leucaena should be sown in North and Central Florida at the beginning of the rainy

²Othman did not use the term "seasonally" but it is added here because of the success of young transplants and survival of seeded plants on seasonally water-logged soils on several sites in South Florida.

season and after the soil has been charged with at least 30 cm (12 inches) of water. In South Florida plant after the danger of last frost has passed. Always plant shallow and in heavy soil; do not press the seed with a tilling press wheel as leucaena emergence is slow and hazardous (Larsen, 1994).

Fertilization of leucaena prior to planting should be based on soil test recommendation as for any other summer legume. Maintenance fertilization should not be necessary where leucaena is lightly stocked. Where stocking rates are high or where it is cut and carried, leucaena will more than likely need yearly applications of fertilizer. Its deep rooted nature on well-drained soils has facilitated the mining of nutrients. In the Gainesville world collection soil pH dropped from 5.5 to 5.4 over 15 years and only phosphorous levels declined (Cunilio, personal communication). The best indicator of any nutrient deficiency is a tissue analysis (Section 8.5: Chemical Composition).

8.3 Management: The herbage is grazed or cut and fed fresh but satisfactory haylage, silage and meal can also be prepared. Leucaena herbage is cut 2-8 months after establishment and repeatedly cut when it reaches 90-150 cm (35-60 inches) (Bogdan, 1977). For pasturing leucaena, the Australians recommend either grazing hedgerows short (when material is no higher than 2-3 m) or allowing some stems to grow out of reach of the cattle (over 4 m) and grazing continuously thereafter (Partridge, 1989). In Brazil with hedgerows kept at 3 m (10 ft), grazing is light during the first year to allow strong root development. In the second and subsequent years leucaena is rested for about 6 weeks after heavy grazing (Raymon, 1994). Tall, giant-type leucaenas can be grazed all year round at wide hedgerow spacing. The canopy keeps the plants growing while the cattle eat the lower side branches and the masses of young seedlings. Cattle will ride down the stems that can be bent over so it will take 3 or 4 yrs before the stems are heavy enough to protect the tops. A productive stand over 30-years-old has been described in Australia (Partridge, 1989). In general, leucaena should be managed carefully to provide early spring and late fall grazing when the quality of other feed is low.

8.4 Herbage Productivity: Forage productivity is a function of plant population and management. For total plant measurements, yields at low populations (10,000/ha or 4,000/A) are responsive to the height at which plants are cut from the ground. In Brazil, total biomass and total edible forage fraction were greatest (32 Mg/ha and 19.8 Mg/ha, respectively) when the material was cut at 60 cm (23.6 inches). The crude protein fraction was 21.5% (de Lucena, 1991). The earliest work in Hawaii meanwhile, found that high populations (173,000/ha or 70,000/A) cut close to the ground produced highest yields or 26 t/ha fresh weight (Takeketha and Ripperton, 1949). It must be noted here that the Brazilian study cited here used the improved variety Cunningham whereas the Hawaiian workers in 1949 planted the bushy, low-growing unimproved type. In Hawaii, some ten years later, Kinch and Ripperton planted an undescribed leucaena variety at 36 lbs of seed per acre resulting in at least as high a plant population as cited above (173,000/A). Yields of green whole-plant forage cut on average 4.6 times per year from this second Hawaiian study averaged 32.7 tons/A (Kinch and Ripperton, 1962). This material was also cut close to the ground. One could conclude from this discussion of cut forage, plant population and height of cutting that the giant leucaenas are better managed when harvested well above-ground level. Is this also true at high population? In

Taiwan, total edible fresh weight as a percentage of total herbage fresh weight yield from K28 (a giant type) increased as plant population increased from 50,000 to 200,000 plants/ha. Maximum fresh weight yield was 40.8 tons/A. Rainfall in Taiwan averages 86 inches per year. Plants were cut four times per year for five years at 23 inches above the ground. Edible fresh weights ranged between 54% and 62% of total fresh weight (Shih et al., 1989). Dry matter to 10% moisture is usually 24% of fresh weight.

If seed availability were not a problem, it would appear that population of at least 50,000 plants/ha (20,000 plants/A) can produce comparable edible fresh weights. Cutting giant leucaena for fodder from rows wide enough to accommodate machinery would be more than an agricultural endeavor; it would require an agro-industrial initiative. The economics and technology of such a system can be found described in Kinch and Ripperton's Hawaiian work in 1962.

Which brings this discussion on management to rotational grazing. The important difference between edible and nonedible forage was studied by Osman (1986) in Mauritius (59 inch of rainfall). A five year study of leaf-stem ratio with widely-spaced hedgerows from the intermediate Peru-type leucaena (more side branching than giant-type) revealed the following: 1) the relative edible dry matter peaks at 90 days; 2) the leafiness in leucaena remains at a sustained level over a long period between 90 and 120 days; 3) leaf to stem ratio falls off dramatically at 150 days and 4) very young growth of leucaena (30 days) contains a very high proportion (2/3) of the dry matter in the leaves (Osman, 1986). Since crude protein is highest in the young leaves and cattle have been observed to prefer fresh over older growth, a grazer especially will wish to grow wide hedgerows with near-solid leucaena well established before being grazed or cut at 30 inches to promote new growth.

In summary, a high plant density between row spacing seems to favor fastest growth and highest leaf production with leucaena. The wider the rows, the more adaptable the plant becomes for grazing. The more narrow the rows (to a limit of 21-36 inches) the more adaptable the plant will be for cut fodder. In pastures with wide hedgerows, leucaena grows indefinitely in association with such grasses as rhodesgrass, the paspalums, pangola or Bermuda provided grazing is properly controlled. Tall, bunch grasses like elephantgrass (*Pennisetum purpureum*) Napier or sugarcane (*Saccharum* spp.) would probably suppress the yields of leucaena if planted in the same year.

8.5 Chemical Composition: Crude protein (CP) content in the majority of references in Bogdan (1977) range from 15 to 25 percent in the DM for the whole herbage as fed to the animals. The content of crude fiber (CF) usually fluctuates from 33 to 38 percent, of NFE from 35 to 44 percent and CP and CF contents in the leaves are given as 28.8 and 12.8 percent, respectively. CP content varies with plant age which in turn depends on the frequency of cutting. Deficiencies in the contents of tryptophane and in sulphur-containing amino acids have been noted. The contents of Vitamin A and C are normally high.

More recently, in Hawaii, Austin and his colleagues analyzed twenty leucaena genotypes deemed superior for forage and found them to contain, in the edible portion, nutrient means above National Research Council requirements for a 375 kg (827 lb) pregnant yearling heifer gaining 600 gms (1.3 lbs) [(Table 8.1.) (Austin, 1992). Only sodium, copper and zinc were found to be slightly below the required standard. They concluded that not only are many leucocephala genotypes outstanding in chemical composition but other leucaena species like *L. pallida* and

its hybrids are also noteworthy.

Table 8.1. Means and ranges of nutrient concentration of 20 *Leucaenas* spp. genotypes compared with values from other studies (Austin et al., 1992).

Element (unit)	This study		Other study		Reference
	Mean	Range	Mean	Range	
Phosphorus (%)	0.28	0.17-0.35	0.24	0.20-0.28	Othman et al. (1985)
Potassium (%)	2.0	1.3-2.5	0.24	0.23-0.28	Austin (1991)
			2.2	0.79-2.59	Akbar and Gupta (1984 and Othman et al. (1985)
Calcium (%)	1.20	0.74-1.95	0.98	0.76-1.20	Othman et al. (1985)
Magnesium (%)	0.22	0.16-0.34	0.27	0.24-0.31	Othman et al. (1984)
Sodium (%)	0.03	0.02-0.08	0.03	0.02-0.04	Akbar and Gupta (1984)
Manganese (ppm)	49.4	30.5-93.0	33	24-79	Gupta et al. (1986)
Iron (ppm)	161	73-241	112	61-485	Gupta et al. (1986)
Copper (ppm)	6.8	3.0-11.0	5	3.8-8.7	Gupta et al. (1986)
Zinc (ppm)	24.2	17.5-31.5	13.0	10.5-18.4	Gupta et al. (1986)
Boron (ppm)	53	35-67	---	---	---
Aluminum (ppm)	58	12-120	---	---	---

The low sodium content in leucaena revealed by the work in Hawaii is born out by work done in Australia where production is on the rise. Sodium and iodine (also said to be deficient in Australia) is found in the grasses especially pangola and rhodesgrass if planted in the alleys. New leucaena shoots in Australia were found to contain 75% highly digestible dry matter with 25% crude protein content. Cattle are said to eat leaves, young stems to about 5 mm in diameter, the flowers and seed pods. All are excellent sources of protein and minerals and will not cause bloat (Partridge, 1989).

Work by Othman in Gainesville, Florida, USA, on mineral composition of leucaena from 12 accessions produced from two harvests had higher than adequate levels of N, P, K, Ca and Mg for feeding all classes of cattle including dairy (Othman, 1985).

In India, where a great deal of work has been done with leucaena over the last decade, leaf meal is traded internationally and must meet rigorous standards for the poultry industry. Leucaena is extremely high in carotene with a minimum in Hawaii of 204 ppm (Kinch and Ripperton, 1949). Table 8.2 presents the chemical composition of five species of leucaenas in India. "LL" represents two leucocephalas: K8 and K28. Crude fiber would be expected to be higher if some coarse stems were used along with the mature leaves.

TABLE 8.2. Chemical Composition of Different *Leucaena* Species (%)*

Parameters	LE	LT	LP	LL	LD
Moisture	65.2	66.1	65.2	66.3	64.3
Dry matter	34.8	33.9	34.8	33.7	35.7
Crude protein	24.9	24.0	25.0	24.2	24.0
Fat	5.9	5.6	6.1	6.0	5.2
Crude fiber	22.9	22.7	20.4	22.0	22.0
Total ash	7.2	7.4	7.6	7.7	7.6
Carbohydrate	39.1	40.3	40.9	41.0	41.1
Calcium	2.1	2.0	2.1	2.0	2.0
Phosphorus	0.2	0.1	0.1	0.1	0.2
<i>In-vitro</i> digesta- bility matter	53.0	50.0	48.0	51.0	52.0
Mimosine	NA	NA	3.9	4.0	4.1

LE = *L. esculenta* LP = *L. pulverulenta* LT = *L. trichoides* LL = *L. leucocephala* LD = *L. diversifolia*

*Values reported on dry matter.

The final parameter measured from Table 8.2 above is mimosine. Mimosine is a toxic, nonprotein amino acid found to range from 2 to 6% in leucaena dry matter (Bogdan, 1977). In ruminants, mimosine is converted by ruminal microorganisms to a compound called DHP (3-hydroxy-4(1H)-pyridone(3,4,-DHP) which is a potent goitrogen. When healthy animals were found in St. Croix, US Virgin Islands, grazing abundant leucaena, researchers imported some of the animals (Senepols) along with their rumen microorganisms in order to identify the bug which was allowing the host to avoid the classic toxic symptoms of mimosine toxicosis. Typical signs of toxicosis include alopecia, anorexia, reduced weight gains or weight loss, excessive salivation, esophageal lesions, large thyroid gland and low circulatory concentrations of thyroid hormones (Hammond, 1989). The DHP-degrading bacteria were indeed found in the rumen, studied over a long period of time, finally isolated, identified and named as a new species. A major breakthrough had been achieved. Freeze-dried DHP-degrading bacteria were soon sent to Brazil where they were sorely needed. But if cattle only gradually eat leucaena, they will not experience the problems noted (Partridge, 1989).

8.6 Animal Production: Information on animal production is somewhat erratic. Hill in his review from Australia reports that steers grazed leucaena gained 200 to 522 gms/day (1.15 lb/day). Plunket in Hawaii observed direct correlation between rainfall and live weight gains in steers grazed at one animal to 0.8 ha; the animals gained 233, 171 and 90 kg/ha (513, 376 and 198 lb/A) in the years with 1800, 860 and 510 mm (70, 33 and 20 inches) of rain, respectively. He also reports that an irrigated leucaena, *Panicum maximum* pasture gave 400 kg/ha (178 lb/A) annual live weight increase and cows grazed on the same mixture produced

9,770 kg (21,538 lbs) milk/ha/year, the maximum annual production reaching 4,900 kg (10,802 lbs) milk/cow, 12 kg (26.5 lb) being the average daily milk yield per cow (Bogdan, 1977).

More recent information from Brazil and Australia has recorded average gains of 700g (1.4 lb)/head/day and 1,000 g (2.2 lb)/head/day, respectively. The Brazilian animals were 8-month-old steers while the Australian beasts were described merely as steers. Carrying capacity varied according to season of the year in both countries. Older animals in Brazil have gained 1 kg (2.2 lb)/day on leucaena (Raymon, personal communication). In Australia, it is stated by an officer of the CSIRO that "No other tropical pasture legume has put as much weight on steers as leucaena, especially at high stocking rates" (Partridge, 1989). Compared to heavily fertilized Siratro pastures leucaena-based pastures have resulted in steers gaining over 200 kg (440 lb)/head/year vs. 180 kg (396 lb) even at half the stocking rate. Milking cows can benefit from the high protein feed as well as mentioned above. More recent information from Australia from the dairy sector in Australia is highlighted by a 6,300 kg (13,889 lb) milk/head yield from Jersey cows on a leucaena/green panic (*Panicum maximum*) pasture over a 9-month period with 4½ cows/ha and no supplement (Partridge, 1989).

In Ona, in 1994, it was learned that young cattle could not be coaxed into a leucaena paddock and preferred staying out on a Bahia pasture early in the year. By summer, however, the animals having access to the leucaena came to relish it (Kalmbacher, 1994). Palatability problems like this have been noted in Hawaii under high rainfall (Kinch and Ripperton, 1949). It should be noted that the leucaena rumen bug described above has not been observed to improve cattle's taste for the plant. It has, however, been available in Australia for over a decade. Over 24,000 acres have been planted in that continent and seed production cannot keep up with demand (Larsen, 1994).

A final note of caution to the producer: leucaena which is maintained for high leaf production, i.e., dense hedgerows or stands grazed or cut frequently in the humid summer months especially, will eventually attract the psyllid and encourage its rapid multiplication. There are, as noted in Chapter 2, leucaena varieties and species which tolerate psyllid attack better than others. Seed of these varieties and species should be used in a mixed planting to reduce the risk of heavy infestation. As stated previously however, Florida's unique subtropical climate with its accompanying cool season has made the psyllid threat less grave than in other parts of the world where frosts do not occur.

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Production and Management of Biomass/Energy Crops on Phosphatic Clay In Central Florida¹

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INTRODUCTION

Biomass/energy crops have performed exceptionally well on phosphatic clay in central Florida. Total dry matter yield of selected sugarcane and elephantgrass varieties have averaged in the range of 20 to 25 tons (80 to 100 tons fresh weight) per acre per year over 4 years. Even higher yields have been observed with Erianthus. These yields were obtained with one harvest per year. Yield trends of some biomass selections included in one of two 4-year studies increased during the study while others declined. With one harvest per year, stand life for most of these crops will be 6 or more years. Biomass crops can be utilized in ethanol or methane production or by direct burning to produce energy.

Today, there is great concern about carbon dioxide (CO₂) buildup in the atmosphere related to global warming. One acre of pre-harvested biomass can remove more than 50,000 lbs of CO₂ each year.

If the biomass is grown using sludge or other organic sources of nitrogen, this CO₂ is recycled from the atmosphere, with no net addition, when energy crops are harvested and utilized.

Phosphatic clay is a by-product of phosphate mining. Phosphate ore is a matrix of sand, clay, and phosphate minerals. Clay is washed from the ore matrix in the beneficiation process and pumped to large settling areas. After a settling area is filled, it is reclaimed by creating perimeter and lateral ditches to drain and allow the surface to dry. Additional drainage in the form of sloped beds is needed on flat, poorly drained settling areas (see IFAS publication SS-MLR-01 Guidelines for Reclaiming Phosphatic Clay Settling Areas for Intensive Agriculture). As of December 31, 1991 there were 102,172 acres of phosphatic clay in Florida, and this acreage is increasing by about 2,000 acres each year. As of December 1991, a total of only 10,311 acres, 10 percent of the 102,172 acres of phosphatic clay, had been reclaimed (Source: Florida Dept. of Natural

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Resources (DNR), Bureau of Mine Reclamation). Reclamation and improved drainage of phosphatic clay land is expected to increase dramatically in the future.

Phosphatic clay as a man-made soil is unique in Florida, compared with natural soils that are typically sandy or organic in nature. Since most native Florida soils are infertile and have low water holding capacity, a considerable amount of energy in the form of fertilizers and irrigation are required to grow biomass crops successfully. In contrast, phosphatic clays have high fertility and water holding capacity, reducing the need for irrigation and fertilization other than nitrogen. No fertilization is needed for legume crops. Crop production on phosphatic clay soil requires low energy input which increases the incentive for biomass crop production.

SOIL PREPARATION

The site selected to grow energy crops should have good surface drainage. The drainage system should remove all standing water within 24 hours of a heavy rain. Before planting time, at least 4 to 6 weeks should be allowed for soil preparation. Time is needed to kill weeds and grasses, if chemical cultivation is used, or for clods to break down, if using mechanical cultivation. Soil should be reasonably level and free of all weeds and grasses at planting. Mechanical cultivation, chemical cultivation or a combination of both may be used.

Mechanical cultivation may consist of primary tillage with a moldboard plow followed by secondary tillage with a power tiller or disc harrow. Rain events occurring between tillage operations will help break up clods and hasten development of a firm, level seed bed. It may be necessary to spot treat bermudagrass with one or more applications of herbicide should it be present. Bermudagrass is not easily controlled with tillage alone.

A seed bed may be prepared with one or two applications of a systemic herbicide such as glyphosate (*Roundup*), fluazifop-butyl (*Fusilade*), or sulfosate (*Touchdown*). A combination of herbicide and light disking is another way of preparing the soil for planting.

CROP SELECTION

Perennial crops that regenerate annually from buds at the base of the plant offer the greatest potential for energy-efficient production in central Florida. A number of these crops have been studied on phosphatic clay as a part of the research activities of the Mined Lands Agricultural Research/Demonstration Project. Crops include: elephantgrass (*Pennisetum purpureum* L.), energycane (*Saccharum* sp.), sugarcane (*Saccharum* sp.), Erianthus [*Erianthus arundinaceum* (Retz)], sweet sorghum [*Sorghum bicolor* (L.) Moench], forage sorghum [*Sorghum bicolor* (L.) Moench], and leucaena [*Leucaena leucocephala* (Lam.)] (Table 1).

Elephantgrass, energycane, sugarcane, and Erianthus are tall-growing, stiff-stemmed bunchgrasses. These plants have the ability to generate high leaf masses to totally intercept and utilize available sunlight in the later stages of the growing season. Erianthus tends to be more difficult to establish than elephantgrass or sugarcane. It also has a spreading growth habit which could create harvesting problems.

Sorghum is an annual tropical grass with large genetic variation. Sweet sorghum has been selected for its sugar content and is normally grown for molasses production. Forage sorghum has been selected for high yields of reasonably good quality animal feed. Sorghum varieties producing tall plants with large stems make the best candidates for biomass production. Both sweet and forage sorghum have a high potential for lodging. Lodging can result in harvest problems with ensuing loss of yield from both initial and ratoon crops.

Leucaena is a shrub-like tropical legume not requiring nitrogen fertilization. However, leucaena requires several years of growth before approaching maximum annual yield. The plant is woody and may have to be harvested with hand labor since mechanical harvesting equipment is not readily available.

PLANTING

Elephantgrass, energycane, sugarcane and Erianthus are all propagated from stem pieces. These perennial grasses may be planted either in late summer (weather permitting) or in the fall (Table 2). Summer planting should be completed no later than September 15th to avoid plant death due to freezing

Table 1. Dry matter yield of biomass/energy crops grown on phosphatic clay - 4 year average.

Crop	Accession	Ton/acre	Yield trend ^a
Elephantgrass ^b	PI 300086	21	Increase
Elephantgrass ¹	N51	20	decrease
Energycane ¹	L79-1002	19	decrease
Energycane ¹	US72-1153	22	increase
Energycane ¹	1K-7647	22	(3 year data)
Sugarcane ¹	US78-1009	22	decrease
Sugarcane ¹	US56-9	23	variable
Sugarcane ¹	CP72-1210	24	variable
Erianthus ²	IK 76-63	60	Increase
Sweet Sorghum ²	USDA M81E	13	(2 year data)
Forage Sorghum ²	Pioneer 931	17	(2 year data)
Leucaena ²		26	Increase
^a Trend of yields over 4 year period when data available.			
^b Average of yields from two studies.			
¹ Source: Prine, et al., 1990			
² Source: Mislevy, et al., 1989			

weather during the first winter. Summer planting has the advantage of producing a full harvest within 14 months. Disadvantages of summer planting include risk of having soil preparation and planting schedules disrupted by frequent rains; and, also, poor utilization of seed material because of immature growth. Seed material comes from a growing crop that will not mature until fall.

Fall is the best time for planting perennial grasses. Planting can begin in early November and continue until a killing frost. Frost will destroy the planting material. Stem pieces planted in November and later will grow slowly with cool soil temperatures. Although a freeze may burn off leaves that have emerged, the growing point of the plant will remain below the soil surface. The young plants will survive and continue to grow.

Both sorghum and leucaena are propagated from seed. Sorghum may be planted from mid-March through early August. Sorghum planted in mid-March may be harvested two and possibly three times per year. Later plantings will only produce one or two

harvests. In general, the later the planting the lower the yield potential.

Leucaena may be planted from April through July. Planting before the start of the rainy season may require supplemental irrigation for good plant emergence. Planting during the rainy season may result in difficulty in preparing a seed bed due to wet soil conditions.

Row spacing is of concern especially for harvesting equipment. If forage harvesting equipment is to be used, row spacing should match that of the harvester, usually 38 to 48 inches. If a cane harvester, similar to those used in south Florida, is used, row spacing of 60 inches will be required. Row spacing influences biomass composition. Generally, wide row spacings result in higher sugar content of tall grasses and canes with lower fiber content. However, narrower rows increase stand density which results in higher biomass yield, lower sugar, and greater fiber content.

Table 2. Recommended planting dates for biomass/energy crops in central Florida.

Crops	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Perennial grasses	X							X	X		X	X
Sorghum			X	X	X	X	X	X				
Leucaena				X	X	X	X					

For vegetatively propagated perennial grasses, furrows should be made with a plow or middle buster (two-way plow). Furrows should be 5 to 6 inches deep for sugarcane and 2 to 4 inches deep for elephantgrass. Canes should be cut so there are 2 or 3 nodes on each piece and placed in the furrow with two canes side by side. About 4 to 5 tons of canes will be needed to plant an acre.

Covering furrows can be difficult in phosphatic clay because clods may be formed during furrowing. A co-rotational power tiller (e. g., Lely Roterra or one made by Befco) has been used with good success when the tines are run at a depth of 2 to 3 inches. A peg tooth harrow pulled at a 45° angle to the furrows is also effective.

Sorghum and leucaena may be planted with a conventional plate-type corn planter. If a plate-type planter is used, it is necessary to find the correct size plates for the seed being planted. A plateless planter would be the easiest to use because the planter adjusts to different seed sizes without the need for plates. Ten lbs of seed per acre is recommended for both forage and sweet sorghum.

Leucaena seed is about the size of small watermelon seed. The seed should be scarified with acid, sodium hydroxide, or with boiling water to improve germination. It should also be inoculated with a specific rhizobium (e. g., *Inoculum L*⁴ marketed by the Nitragen Co., Inc., Milwaukee WI) and planted 24 to 36 inches apart in the row with 2 - 3 seeds per drop. Finding adequate supplies of planting materials for large plantings of elephantgrass, energycane, Erianthus, and leucaena, on short notice, will be difficult. These crops are not grown in commercial quantities. It will be necessary to build up a stock of planting materials by planning ahead and establishing nurseries of species and varieties desired. For planning purposes, figure that one acre

of perennial grass nursery will plant 10 to 15 acres (4 to 5 tons of canes planted per acre) 12 months from original planting, provided the nursery is well managed. Some commercial sugarcane varieties, such as CP72-1210 are grown in South Florida and planting material may be obtained from growers in that area. Leucaena seed is also not commercially available. A small amount of seed is available from people doing research with leucaena. Leucaena seed is presently harvested by hand. Sorghum seed, however, is readily available from commercial sources.

WEED CONTROL

Once these biomass crops are established to a good stand they will be able to compete against weeds and grasses. However, weed control may be needed during the establishment phase. A pre-emergent herbicide such as atrazine (*Atrazine*) or atrazine and metribuzin (*Atrazine* and *Sencor*) should be used. Check the IFAS Weed Control Guide for the latest recommendations on herbicides and follow label directions.

FERTILIZATION

Phosphatic clays have a high soil pH (>7.0) and high P, K, Ca, and Mg. levels. Only nitrogen is required for fertilization. Nitrogen recommendations for perennial grasses and sorghum is 160 to 200 lbs of N per acre per year. Leucaena, being a legume, requires no additional nitrogen. Nitrogen may be supplied in an organic or inorganic form or a combination of both. Common forms of inorganic nitrogen include ammonium nitrate (32% N), ammonium sulfate (21% N), or urea (45% N). Organic N sources include compost, animal manures, and sludge from municipal waste water treatment. Urea should only be used if it is soil incorporated or banded to a depth of >3 inches to prevent volatilization and loss of nitrogen to the atmosphere.

Since neither phosphorus nor potassium is needed on phosphatic clay, only nitrogen will be discussed. Due to the close proximity of the phosphate mining area to a number of metropolitan areas, there is an opportunity to use municipal sludge as an economical source of nitrogen. Application of municipal sludge is regulated by the Florida Department of Environmental Regulation (DER) (Chapter 17-640 F.A.C.).

Municipal sludge comes in three forms: liquid, cake, and dried. Liquid sludge has only 1 to 3% dry matter, cake sludge has a dry matter content of 10 to 20% and dried sludge has 90 to 95% dry matter. Nitrogen content mostly falls in the range of 3% to 8% on a dry weight basis. Sludge and compost is usually hauled to the field at no cost to the grower. Typically, the grower either spreads the material himself or pays the hauler for land-spreading.

A number of factors must be considered when calculating the amount of sludge to apply per acre to supply the desired amount of nitrogen. These factors include the amount of moisture in sludge, percent of nitrogen present, amount of nitrogen available to the crop in the current application plus carryover from previous applications, if any (Figure 1). Although the example in Figure 1 uses cake sludge, the same procedures apply to other organic materials.

Earlier studies on phosphatic clay have shown that municipal sludge is a dependable source of nitrogen for growing crops. When surface applied, about 45% of the nitrogen in municipal sludge is available to the plant in the first year. The remaining 55% of the nitrogen carries over to the second and third year at about 50% of the remaining amount each year.

HARVEST MANAGEMENT

Harvesting perennial grasses and sorghum with large capacity silage equipment will likely be the most labor efficient way of handling these crops. A stubble height of 2 to 3 inches should be left so the crop will ratoon (grow the next crop) properly. Leucaena, being a woody plant, will require hand harvesting and chipping. It may also be possible to adapt specialized equipment from the forest industry to harvest and handling of leucaena for energy production.

Figure 1. Sludge Application (lbs. per acre).

1. (Nitrogen needed/acre/year) + (amount (45%) available 1st year) = (total nitrogen/acre/year)
2. (Total nitrogen/acre) - (nitrogen carried over from previous year(s))^a = (net nitrogen/acre)
3. (Net nitrogen/acre) + (percent nitrogen (dry matter basis) in sludge) = (total dry matter/acre)
4. (Total dry matter/acre) + (percent dry matter in sludge) = (pounds of wet sludge to apply/acre)

^a Nitrogen carryover = (Total nitrogen/acre applied 2 years ago) × (.14) + (total nitrogen/acre applied 1 year ago) × (.27) = (nitrogen/acre carried over from previous years)

Example

Need 200 lbs N/acre on a crop to be supplied by cake sludge with 14% dry matter, and 6.5% nitrogen (dry matter basis). Four hundred fifty (450) lbs total nitrogen/acre applied two years ago and 400lbs/acre last year.

1. Nitrogen needed (200) + (.45) = 444 lbs total nitrogen
2. Total nitrogen (444) - carry over (171) = 273 lbs net nitrogen
3. Net nitrogen (273) + % nitrogen (.065) = 4,200 lbs dry matter
4. Dry matter needed (4,200) + % dry matter of sludge (.14) = 30,880 lbs wet sludge per acre (15.0 tons)

Calculating nitrogen carryover

1. Two years ago (450) × (.14) = 63
2. One year ago (400) × (.27) = 108

Total carryover = 171 lbs

ENERGY REQUIREMENTS

Energy is an important economic and environmental component in the production of agricultural products, especially the manufacture and transport of fertilizer materials. Use of readily available waste products as a source of plant nutrients can have both an environmental and economic benefit. The phosphate mining area in central Florida is located close to several metropolitan areas and the disposal of municipal sludge presents a problem.

A comparison was made between the amount of energy required to supply 200 lbs of actual nitrogen from either ammonium nitrate (34% N) or from municipal sludge. Assumptions were: Sludge contains 6.5% nitrogen on a dry matter basis and is transported 40 miles (one way) from the waste water treatment plant to the field. The quantity of material

hailed per load is enough to supply N to one acre of land. Ammonium nitrate is hauled 15 miles from the plant to the field and enough material is hauled to supply N to 75 acres of land. The hauling distances for the two materials and the quantity hauled is considered typical for this area. All cultural practices other than nitrogen source and method of land spreading are the same.

Energy required for using ammonium nitrate was 81% greater than that needed for sludge (Table 3). The greatest energy requirement when using sludge was fuel for hauling sludge from the water treatment plant to the field. The greatest energy requirement for ammonium nitrate was for the manufacture of the material itself.

Table 3. Energy used to establish one acre of sugarcane or elephantgrass with two nitrogen sources.

Activities/ Inputs	Energy Used to Supply Nitrogen from Different Sources, GDFE*	
	Sludge	Ammonium Nitrate
Soil Prepare and plant	9.9	9.9
Transport fertilizer	20.0	0.1
Spread fertilizer	3.3	0.2
Ammonium nitrate	—	51.7
Atrazine	2.2	2.2
Total DFE	35.4	64.1
*Gallons of Diesel Fuel Equivalent (GDFE): energy inputs equal to the energy in gallons of diesel fuel listed.		

ESTABLISHMENT COSTS

Once established, a stand of perennial biomass/energy crop is expected to remain productive for a period of 6 years or more. Establishment costs are averaged over the expected life of the stand. Annual maintenance, harvest, and handling costs are added to the prorated establishment costs. Because of limited space in this paper, the discussion here

focuses on estimated costs for establishing an acre of sugarcane or elephantgrass (Table 4).

A computerized budget generator developed by the Food and Resource Economics Dept. at the University of Florida was used to estimate costs for this analysis. Field operations for seed bed preparation included plowing with a moldboard plow, tilling once with a co-rotational power tiller, followed by a disc harrow and then two passes with a spring-tooth harrow. Planting operations included plowing furrows with a two-row middle buster then planting seed cane by hand. Furrows were covered with a co-rotation power tiller and the field was then sprayed with a pre-emergent herbicide. No irrigation was used since it was assumed the crops were planted in late November and would develop slowly in cool soil, providing ample time for rain adequately supply water.

Municipal sludge cost slightly less than ammonium nitrate as a nitrogen source. It was assumed that the municipal sludge was transported to the field at no cost to the grower and that the grower was responsible for spreading. Should the grower be required to pay for transporting the sludge, the economic outcome would likely be in favor of the ammonium nitrate.

While it appears that biomass/energy crops may be successfully grown on phosphatic clay, a processing facility is needed to convert the biomass to energy in the form of methane, ethanol or direct combustion. Without an appropriate facility, there is no market for the crop. Presently, ethanol is in demand for use with gasoline to make gasohol and there is a market for ethanol in central Florida. A facility is presently operating with conventional technology to produce ethanol. With conventional technology, only the sugars/starches in juice pressed from the crop can be fermented into alcohol. A crop yielding 20 ton of dry weight (80 tons of fresh material) per acre yields about 800 gal. of ethanol per acre. Technology is being developed that will convert cellulosic materials as well as sugars/starches to ethanol. With this new technology, 20 tons (80 tons fresh weight) of material may yield as much as 2,500 gal. of ethanol per acre.

Table 4. Estimated cost for establishing one acre of sugarcane or elephantgrass on phosphatic clay with two nitrogen sources.

Item	Nitrogen source		Variable costs:
	Sludge	Am. nitrate	
Atrazine	24.00	24.00	8 lb./acre
Ammonium nitrate 34%	--	43.20	588 lb./acre
Municipal sludge (wet)	--	--	30,000 lb./acre
Seed cane	200.00	200.00	5 ton/acre
Machinery costs (sludge)	32.37	--	3.81 hr/acre
Machinery costs (Am. Nit.)	--	24.10	3.22 hr/acre
Machine labor (sludge)	20.93	--	3.81 hr/acre
Machine labor (Am. Nit.)	--	17.73	3.22 hr/acre
Hand labor - planting	116.20	116.20	20 hr/acre
Interest	94.44	102.03	8% for 3 yrs
Total variable costs	487.94	527.26	--
Machinery (sludge)	29.19	--	3.81 hr/acre
Machinery (Am. Nit.)	--	23.87	3.22 hr/acre
Supervision @ 22% of labor cost	30.16	29.46	--
Overhead @ 5% of Var. cost	24.39	26.36	--
Total fixed costs	83.74	79.69	--
Total establishment cost/acre	571.68	606.95	--
Average annual cost over 6 years	95.28	101.16	--

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Appendix D

Field Operations and Materials Used for Each Crop and Soil

D.1 Field Operations and Materials

Crops: Sugarcane, & Elephantgrass on Phosphatic Clay

Assumptions:

- * The costs for drainage and land improvements, including irrigation wells are capitalized into the value of the land
- * Seed material (elephantgrass & Sugarcane) may be harvested or purchased for \$40.00/ton
- * Over the long term, 1/2 of planted acres will receive adequate rainfall for germination
- * Because of drainage ditches, one acre in 12 will be in field margins or drainage ways
- * Row width is 48 inches

Field operations - establishment

10/15/94 Plow - 125 hp tractor & 5 bottom plow, 3.5 mph
10/20 Disc - 125 hp tractor & 16 ft disk, 3.5 mph
10/20 Harrow - 100 hp tractor & 25 ft spring tooth harrow, 5 mph
11/10 Harrow - 100 hp tractor & 25 ft spring tooth harrow, 5 mph
11/10 Open furrows - 125 hp tractor & 16 ft middle buster (4 row), 4 mph
11/10 Plant - by hand, 35 hp tractor & wagon 20 hrs of labor/acre, width 4 ft, .41 mph
Seed material 5 tons/acre @ \$40.00 per ton
11/10 Close furrows - 125 hp tractor & roterra 10 ft, 1.5 mph
11/11 Cultipack - 36 hp tractor & cultipacker
11/12 Herbicide - 36 hp tractor & herbicide sprayer, 16 ft., 4 mph
4 lb (AI) of atrazine per acre
11/15 Irrigate 1/2 of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun
\$23,500 250 ft wide, .024 mph to put on 1 inch of water. (results to be divided by 2
because only 1/2 of area is to be irrigated)

- maintenance

12/15 Fertilize 120+0+0 - 100 hp tractor & broadcast spreader, 5 mph
1/15/95 Maintain ditches - 125 hp tractor & V-ditcher 220 ft of ditch per acre (width 99 ft) 6 mph
1/15/95 Land rent \$20 per acre
3/15/95 Cultivate 1x - 100 hp tractor & 4 row cultivator, 3.5 mph
7/15/95 Mow field margins - 1 acre for every 12 in crop 100 hp tractor and 10 ft mower 3/86,
\$3,400. (120 ft wide), 3 mph

Sorghum Phosphatic Clay

Field operations

1/15/95 Maintain ditches - 125 hp tractor & V-ditcher 220 ft of ditch per acre (width 99 ft), 6 mph
1/15/95 Land rent \$20 per acre
1/30/95 Plow - 125 hp tractor & 5 bottom plow, 3.5 mph
2/15/95 Disc - 125 hp tractor & 16 ft disk, 3.5 mph
3/14/95 Harrow 2x - 100 hp tractor & 25 ft spring tooth harrow, 5 mph
3/15/95 Plant 35 hp tractor & 4 row planter (12 ft), 3.5 mph

3/16/95 Fertilize 120+0+0 - 100 hp tractor & broadcast spreader, 5 mph
Sorghum seed (Concep treated) 8 lbs/acre

3/17 Herbicide - 36 hp tractor & herbicide sprayer, 16 ft., 4 mph
Herbicide Dual @ 2 lb/acre with Concep treated seed

3/20 Irrigate 1/2 of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun
\$23,500 250 ft wide, .024 mph to put on 1 inch of water. (results to be divided by 2
because only 1/2 of area is to be irrigated)

4/10 Cultivate 1x - 100 hp tractor & 4 row cultivator, 4 mph

7/15 Mow field margins - 1 acre for every 12 in crop 100 hp tractor and 10 ft mower 3/86,
\$3,400. (120 ft wide) 3 mph

Leucaena Phosphatic Clay

Field operations - establishment

1/30/95 Plow - 125 hp tractor & 5 bottom plow, 3.5 mph

2/15/95 Disc - 125 hp tractor & 16 ft disk, 3.5 mph

3/14/95 Harrow 2x - 100 hp tractor & 25 ft spring tooth harrow, 5 mph

3/15/95 Plant 35 hp tractor & 4 row planter (12 ft), 3.5 mph
Seed 5 lb/A @ \$15/lb including scarifying

3/16/95 Herbicide - 36 hp tractor & herbicide sprayer, 16 ft., 4 mph
Herbicide Dual preemerge @ 2pts/A

3/17/95 Irrigate 1/2 of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun
\$23,500 250 ft wide, .024 mph to put on 1 inch of water. (results to be divided by 2
because only 1/2 of area is to be irrigated)

4/30/95 Cultivate 1x - 100 hp tractor & 4 row cultivator, 3.5 mph

- maintenance

1/15/95 Maintain ditches - 125 hp tractor & V-ditcher 220 ft of ditch per acre (width 198 ft), 3
mph

1/15/95 Land rent \$20 per acre

7/15/95 Mow field margins - 1 acre for every 12 in crop 100 hp tractor and 10 ft mower 3/86,
\$3,400. (120 ft wide), 3 mph.

Crops: Sugarcane, & Elephantgrass on Overburden

Assumptions:

- * One acre in 40 is in field margins
- * The costs for drainage and land improvements, including irrigation wells are capitalized into the value of the land
- * Seed material (elephantgrass & Sugarcane) may be harvested or purchased for \$40.00/ton
- * Over the long term, 1/2 of planted acres will receive adequate rainfall for germination
- * Row width is 48 inches

Field operations - establishment

10/15/94 Plow - 125 hp tractor & 5 bottom plow, 4 mph
10/20 Disc - 125 hp tractor & 16 ft disk, 4 mph
10/20 Harrow 2x - 100 hp tractor & 25 ft spring tooth harrow, 5 mph
11/10 Open furrows - 125 hp tractor & 16 ft middle buster (4 row), 4 mph
11/10 Plant - by hand, 35 hp tractor & wagon 20 hrs of labor/acre width = 4 ft, .41 mph
11/10 Seed material 5 tons/acre @ \$40.00 per ton
11/10 Close furrows - 125 hp tractor & roterra, 10 ft., 2.5 mph
11/12 Cultipack - 35 hp tractor & cultipacker, 10 ft., 3.5 mph
11/12 Herbicide - 35 hp tractor & herbicide sprayer, 16 ft. 4 mph
4 lb AI of atrazine per acre
11/12 Irrigate 1/2 of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun \$23,500 250 ft wide, .024 mph to put on 1 inch of water. (results to be divided by 2 because only 1/2 of area is to be irrigated)

- maintenance

12/15/94 Fertilize 150+50+100 - 100 hp tractor & broadcast spreader
03/15/95 Cultivate 1x - 100 hp tractor & 4 row cultivator, 3.5 mph
07/15/95 Mow field margins - 1 acre for every 40 in crop 100 hp tractor and 10 ft mower 3/86, \$3,400. (400 ft wide), 3 mph

Sorghum Overburden

Field operations

1/30/95 Plow - 125 hp tractor & 5 bottom plow, 4 mph
2/15/95 Disc - 125 hp tractor & 16 ft disk, 4 mph
3/15/95 Harrow 2x - 100 hp tractor & 25 ft spring tooth harrow, 5 mph.
3/15/95 Spread fertilizer, 100 hp tractor & fertilizer spreader, 5 mph.
3/15/95 Fertilize 120+50+100
3/15/95 Plant 35 hp tractor & 4 row planter (12 ft), 3.5 mph
3/15/95 Sorghum seed (Concep treated) 8 lbs/acre
3/18/95 Herbicide Dual @ 2 lb/acre with Concep treated seed.
3/18/95 Herbicide - 35 hp tractor & herbicide sprayer, 4.5 mph.

3/18/95 Irrigate all of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun
\$23,500 250 ft wide, .024 mph to put on 1 inch of water.
4/20/95 Cultivate 1x - 100 hp tractor & 4 row cultivator, 3.5 mph
7/15/95 Mow field margins - 1 acre for every 40 in crop 100 hp tractor and 10 ft mower 3/86,
\$3,400. (400 ft wide), 3.5 mph

Leucaena Overburden

Field operations - establishment

1/30/95 Plow - 125 hp tractor & 5 bottom plow, 4 mph
2/15/95 Disc - 125 hp tractor & 16 ft disk, 4 mph
3/15/95 Harrow 2x - 100 hp tractor & 25 ft spring tooth harrow, 5 mph
3/15/95 Herbicide - 35 hp tractor & herbicide sprayer 16 ft., 4 mph.
3/15/95 Herbicide - Dual preplant @ 2pts/A.
3/15/95 Plant 35 hp tractor & 4 row planter (12 ft), 3.5 mph
3/15/95 Seed 5 lb/A @ \$15/lb including scarifying
3/15/95 Irrigate 1/2 of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun
\$23,500 250 ft wide, .024 mph to put on 1 inch of water. (results to be divided by 2
because only 1/2 of area is to be irrigated)
4/20/95 Cultivate 1x - 100 hp tractor & 4 row cultivator, 3.5 mph

- maintenance

1/30/95 Lime 1/3 ton per year, delivered & spread
1/30/95 Fertilize 0+40+80 - 100 hp tractor & spreader 5 mph.
7/15/95 Mow field margins - 1 acre for every 40 in crop 100 hp tractor and 10 ft mower 3/86,
\$3,400. (400 ft wide), 3 mph

Crops: Sugarcane, & elephantgrass on Crop Land

Assumptions:

- * One acre in 40 is in field margins
- * One ton of dolomitic limestone delivered & spread every 4 years
- * The costs for drainage and land improvements, including irrigation wells are capitalized into the value of the land
- * Seed material (elephantgrass & Sugarcane) may be harvested or purchased for \$40.00/ton
- * Over the long term, 1/2 of planted acres will receive adequate rainfall for germination
- * Row width is 48 inches

Field operations - establishment:

10/15 Plow - 125 hp tractor & 5 bottom plow, 4.5 mph
11/01 Harrow 2x - 100 hp tractor & 25 ft spring tooth harrow, 5 mph
11/10 Open furrows - 125 hp tractor & 16 ft middle buster (4 row), 4 mph
11/10 Plant - by hand, 35 hp tractor & wagon 20 hrs of labor/acre width = 4 ft, .41 mph
11/10 Seed material 5 tons/acre @ \$40.00 per ton
11/10 Close furrows - 125 hp tractor & rotterra, 10 ft., 3 mph
11/12 Herbicide - 35 hp tractor & herbicide sprayer, 16 ft. 4.5 mph
2 lb AI of atrazine per acre
11/12 Irrigate 1/2 of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun \$23,500 250 ft wide, .024 mph to put on 1 inch of water. (results to be divided by 2 because only 1/2 of area is to be irrigated)

- maintenance

12/15/94 Fertilize 150+50+100 - 100 hp tractor & broadcast spreader, 5 mph
01/30/95 Dolomitic limestone 500lb per year (1 ton every 4 years) \$7.25/yr
03/15/95 Cultivate 1x - 100 hp tractor & 4 row cultivator, 4 mph
07/15/95 Mow field margins - 1 acre for every 40 in crop 100 hp tractor and 10 ft mower 3/86, \$3,400. (400 ft wide), 3 mph

Sorghum Crop Land

Field operations:

02/15/95 Plow - 125 hp tractor & 5 bottom plow, 4.5 mph
03/15/95 Harrow 2x - 100 hp tractor & 25 ft spring tooth harrow, 5 mph
03/15/95 Fertilize 150+50+100 - 100 hp tractor & broadcast spreader, 5 mph
03/15/95 Plant - 35 hp tractor & 4 row planter sorghum seed (Concep treated seed) 8 lbs/acre (12 ft), 3.5 mph
03/15/95 Sorghum Seed (Concep treated) 8 lbs./ Acre
03/18/95 Herbicide - 35 hp tractor & herbicide sprayer, 16 ft. 4.5 mph w/Dual @ 2 lb/acre with Concep treated seed
03/18/95 Irrigate all of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun \$23,500 250 ft wide, .024 mph to put on 1 inch of water.
04/20/95 Cultivate 1x - 100 hp tractor & 4 row cultivator 4 mph.
07/15/95 Mow field margins - 1 acre for every 40 in crop 100 hp tractor and 10 ft mower 3/86, \$3,400. (400 ft wide), 3 mph.

Leucaena Crop Land

Field operations - establishment:

02/15/95 Plow - 125 hp tractor & 5 bottom plow, 4 mph
03/15/95 Harrow 2x - 100 hp tractor & 25 ft spring tooth harrow, 5 mph
03/15/95 Herbicide - 35 hp tractor & herbicide sprayer, 16 ft. 4.5 mph w/Dual preplant @ 2pts/A
03/15/95 Plant 35 hp tractor & 4 row planter (12 ft), 3.5 mph
03/15/95 Seed 5 lb/A @ \$15/lb including scarifying
03/18/95 Irrigate 1/2 of acreage - pump & (75 hp gasoline) power unit \$12,000 traveling gun \$23,500 250 ft wide, .024 mph to put on 1 inch of water. (results to be divided by 2 because only 1/2 of area is to be irrigated)
04/20/95 Cultivate 1x - 100 hp tractor & 4 row cultivator, 4 mph

- maintenance

01/30/95 Spread fertilizer, 100 hp tractor & spreader, 5 mph.
01/30/95 Fertilizer program 0+50+100
01/30/95 Dolomitic limestone 667 lb per year (1 ton every 3 years)
07/15/95 Mow field margins - 1 acre for every 40 in crop 100 hp tractor and 10 ft mower 3/86, \$3,400. (400 ft wide), 3 mph

Appendix E

Determining Harvest Methods

E.1 Determining Harvest Methods

University of Florida/ NREL Project
Development of Biomass Energy Systems

Task- 2.d. Determine Harvest Methods

Investigator- Richard M. Schroeder

Final Report

1. Procedure to accomplish and data to be developed.

a. Receive data from Team members required for examination of harvesting systems.

The following information was received and/or confirmed from the other Team Members
The number of stems to be harvested per acre; approximate spacing of planting.

Cane-row spacing of 48 inches/1.25 m. Density of stalks about 30,000 per hectare.

Grass- planted for maximum density on 48-inch rows.

Woody plants-10,000 per hectare, probably in 1-meter rows.

The average size of each stem, in diameter and height.

Cane-5 cm maximum, height 3-4m.

Grass-3 cm maximum; height at harvest (once per year)-4 m maximum.

Woody Species-10 cm maximum, height 6 m maximum.

Seasonal restrictions on harvesting.

Cane-harvested annually, in October-February.

Grass- harvested annually, in October through February.

Woody plants-harvested year round, conditions permitting.

Estimate of approximate yield in t DM per ha. upon harvest.

Cane-80 green tons/acre, 18 BDT/acre = ± 40 t DM per ha.

Grass-45 green tons/acre, 15 BDT/acre = ± 33 t DM per ha.

Woody plants-40 BDT/acre, 90 t DM per ha.

b. Develop objectives of the harvesting system

Capacity

Conversations with project developers of both combustion projects and chemical (ethanol) projects show that for facilities to be built, no less than 30,000 BDT, or 60,000 green tons, should be available. Although closed loop dedicated crops may be integrated into existing facilities in smaller quantities, for this study we are examining the feasibility of a new enterprise; therefore, the numbers above will be used for capacity.

The limitation concerning harvesting season (5 months per year) provided by the research personnel at the University of Florida increases the required machinery capacity. About 60,000 green tons (50% Moisture Content) must be harvested in five months, or approximately 125 work days.

It can be argued that this requirement will force operations into 7 days per week, which is closer to 150 days. However, some consideration must be given to transit, and weather-related problems. Therefore, the lower number of 125 was used. Likewise, the months given are those of shortest daylight hours, so no more than 10 operating hours can be assumed on average.

From the information above, for any of the three systems (cane, grass, or woody stems), capacity is needed of $60,000 / 125 / 10 = 48$ tons per hour. At a capacity factor of 80%, this equates to a required capacity of 60 green tons per hour.

Field conditions

The field conditions are considered to be flat, rock-free, subject to flooding and poor traction, with unimpeded access by wide alleys and paved roads. In many of the discussions with equipment manufacturers, reference was made to ground instability, and the need for floatation equipment in the development of the site.

In the environmental and land use study by McConnell, two primary resources were identified; clay-settling areas (CSA's) and mined out areas (MOA's). The CSA's are basically de-watered sludge ponds, while the MOA's are areas where mineral was removed and then the ground somewhat re-leveled.

For both of these land types drainage will be a problem. In Central Florida, the rainfall is traditionally less in fall and winter than in summer, but still many rainfall events of 1" rainfall or more can be expected during the time of harvest.

In addition, the CSA's present another challenge. The ground consists of basically a hardened crust, over a 'bottomless' quagmire of high clay, water-saturated soils. In an interview with Florida Land Reclamation Company, a company specializing in phosphate land reclamation, it was stated that the standards for reclamation of CSA's is that, when complete, they are able to support the weight of "average farm equipment". When pressed for the definition of this, they stated that high flotation wheels on harvesting equipment will most likely be the minimum required. Track-type machines would be better; the land will probably not support conventional on-road type trailers for transport of the material. This information was used in the determination of the machinery required.

Desired Product Characteristics

Most of the uses being considered under this program do not require water contained within the fuel. In combustion, water (or moisture content) is a major problem, leading to inefficiency and emissions issues. In ethanol production it appears to be less critical, but still not necessarily desired.

Therefore, some type of desiccation process will be needed. For this study, it was decided to examine the harvesting from both sides of the issue for grasses and canes. For woody stems, transpiration drying of the stems by advanced felling is a common practice in some areas, and the operations are almost identical for either fresh or desiccated tree harvesting, so only one system is examined.

The equipment will be based on either delivering small ($>3''$) particles, in woody stems, or in both stem and chopped condition for grasses or canes.

Transport Considerations

Transport is being studied in more detail by other Team Members. Based on conversations with the Team Members, no additional data will be developed for this portion of the operation. The operations described will include those steps necessary to place the material into some transport device at the site of harvest or at an adjacent roadside.

Operational Characteristics

The operational considerations identified are ease of operation, parts and service availability, ease of service, and support requirements. These necessarily provide strong incentives to use established equipment compared to prototypes. All machinery identified in this report is in common use.

In the case of the grass equipment, the characteristics of this crop are obviously different than most conventional hay crops. Also, the cane harvester company has developed a machine adapted for harvesting coppice willows in Europe from the standard cane harvester; although this machine is not in widespread use, it was considered as a variant of a widely used machine, and not a prototype.

General Economic Considerations

General economic considerations include the following:

- Resale value of the equipment
- Fuel consumption per ton of harvest.
- Utilization of equipment versus special equipment with low utilization.
- Proven capabilities of the machinery.

All of the above items were considered in selecting the machinery in this report.

It should be noted that machinery types, and not necessarily brands, were targeted in the report. Mower-conditioners and many of the other machines are available from a wide variety of suppliers. It was felt that if information was obtained from one source, that through competition the prices and specifications would probably be similar for different manufacturers of basically the same equipment. Therefore, little time was spent comparing the points and economic values of different models from different suppliers.

c. Review data developed in harvesting trials relating to coppice biomass and grass crop harvesting specific to energy crop harvesting.

Harvesting data and studies have been received from work performed in Ona, Florida, Bartow, Florida, Edinburgh, Scotland, and Hatillo, Puerto Rico. General cost and machinery data has been received from the USDA on sugar cane, from the Texas A & M University on forestry harvesting, from the University of Florida and Louisiana State University on agricultural machinery, and John Deere Equipment Company.

The literature was reviewed to get an overview of the approaches to the general field of biomass harvesting for energy. Although details of the approaches varied, all of the efforts resembled each other to a large degree. This indicated that the industry was freely communicating its findings, and that the equipment manufacturers were steering development into select, more promising directions.

This was confirmed during the conference on Short Rotation Intensive Culture (SRIC) held in Mobile, Alabama during March 1-3, 1994, and in the National Bioenergy Conference in Reno, Nevada, October 3-6, 1994. Based on this review, it is felt that the report covers the main lines of development in harvesting technology.

d. Establish matrix of harvesting possibilities for various crop types, desired processing and operational restraints.

If analyzed to an extreme, one could establish a matrix consisting of the following; three crop types (cane, grass, woody), each of which can be on two land types (CSA or MOA), for each a scenario of dry versus green harvest and whole versus chopped harvest. This figures to be 24 different harvesting possibilities, and excludes such other variables as high labor versus low labor, full-time versus part-time harvesting, etc. From a practical standpoint it is felt that this is an unworkable matrix, and that it needs to focus more on major categories than singular possibilities.

Based on the research performed in this report and ongoing projects within Kenetech, it was decided to list the following possibilities as the preferred harvesting possibilities to be studied:

Cane Types
Billet harvesting.

Chopper Harvesting

Grass Types

Cutting/Drying/Baling

Chopper Harvesting

Woody Species

Chopper Harvesting

Felling/Bunching/Chipping

The information gathered during this investigation indicates that little data is available distinguishing cane chopping from grass chopping from woody chopper harvesting. Therefore, the possibilities to be studied will be further reduced to the following:

Chopper Harvesting

Cutting/Drying/Baling

Billet Cutting

Felling/Bunching/Chipping

An analysis of felling/bunching/chipping shows that this harvesting method is very sensitive to individual stem diameter; i.e., it appears that harvesting trees 4" in diameter are twice as expensive, on a per-ton basis, as harvesting trees 8" in diameter. Although work is being done with saw-type felling equipment that can shear stems without stopping the machine, these have not been proven in extensive field tests.

Also, felling/bunching systems are rarely used and somewhat inefficient when stem size falls below 100 pounds, requiring 20 cycles per ton to harvest. The information received from Don Rockwood in the study group infers rotation ages and densities that suggest lower stem weights than 100 pounds. For these reasons, the conventional method of tree harvesting was deleted from the list of possibilities to study further.

This leaves three that will be analyzed in the report:

Chopper Harvesting

Cutting/Drying/Baling

Billet Cutting

e. Contact manufacturers for specific information on design, construction, and operation of existing harvesting equipment.

During August 1994 interviews were held with licensed dealers of John Deere equipment in Palmetto, Florida, and Atlanta Georgia. During July the authorized dealer of Austoff Cane Harvesters in Belle Glade, Florida was also interviewed. Contacts were made with

users of the Klaas harvester in Europe; however, initial indications from Klaas dealers in the US were that little was known about the Jaguar development.

The information gathered from the dealers not only related to machinery, but to common practices and experience. These observations were considered in the preparation of this report.

We now have three separate harvesting (or collection) techniques to look at. The first will apply to the grasses, and will be derived from conventional haying equipment. The chopper harvesting techniques is a conventional agricultural approach being applied to an increasing range of crop types, and consists of cutting, chopping, and loading the material from the ground into a wagon in one pass. The third method is being used for commercial sugar cane harvesting, and is being tested for coppice willow, and consists of cutting material into lengths called billets. The billets are then left to dry, or are hauled green to the consuming bioenergy operation.

Included in this report are some representative informational brochures on some of the machines described.

f. Discuss prototype development with research institutions and manufacturers.

Early in the project we reviewed activities in Texas on prototype harvesters. We also reviewed manufacturers' R &D activities in Michigan, Finland, Louisiana, Puerto Rico, and the United Kingdom..

Early in this study the objective was established to examine commercially feasible technologies. Prototype harvesting technologies are non-financeable, and therefore do not represent alternatives which are pertinent to this study. For this reason it was decided to forego any further study of prototypes or research on equipment, and to concentrate on existing machinery.

g. Select appropriate equipment scenarios, including the harvesting machine and any support equipment required to best meet the objectives as discussed above.

The University of Florida, in its correspondence dated 9/13/94, requested the information in an outline form, to include the following:

- machine purchase cost
- machine capacity in tons per hour or ground speed
- field efficiency
- expected useful life
- estimated hours of use per year
- expected repair costs/year
- fuel type and fuel consumption

Table One includes a spreadsheet of each harvesting scenario. It lists equipment by individual unit, and predicts the values above for each.

All of the scenarios follow the following approach:

1. The operations are assumed to be independent of other farming operations; i.e., it is envisioned that these are operated by a subcontractor instead of the landowner.
2. The equipment shown is designed to remove the biomass material from the field and carry it to a roadside. The machinery does not include transport; as stated earlier, other Team members are studying this portion. The subject of loading trailers is discussed in each scenario.
3. The equipment does not include supervision or administration; i.e., a utility vehicle and some office equipment would be necessary, but unrelated to the actual harvesting.
4. Many of the fuel consumption numbers are guesses, based on the number of cylinders in the engine or the horsepower. The fuel consumption of diesel engines can vary greatly depending on load, and the load that these new crops will bring to the machinery is uncertain. If anything, the fuel consumption may be over-stated for the tractors, and under-stated for the harvesting equipment.
5. The prices for machinery are estimates received from dealers or literature. They do not include sales tax, but should include delivery costs.

Each of the scenarios is discussed in more detail below.

Scenario 1. Cane/Woody-Harvested in Billets

This case is based around a machine which cuts the stalks in a swath about 1.25 m wide, gathers them as the machine moves forward, and places the stems in a bunk at the rear of machine, for loading into wagons. The wagons then move the stems to locations within one mile of the field, and unload them into long piles where they can dry.

The material is field-dried for 2-6 weeks, although depending on the time of year the material may be able to be stored up to six months without degradation. This allows for farm storage of fuel, instead of requiring storage capacity at the facilities.

It is anticipated that the drying stalks will be between 2 cm to 7 cm in diameter, and approximately 3-4 m long. They will be picked up at the pile sites and chipped, using a drum-type wood chipper. In this case a Morbark Model 36/30 E-Z Chipper was selected, based on the recommendations of the manufacturer. The uniform stem size means that a larger in-feed opening is not required, and the machine must be powerful enough to throw wood chips into the back of a conventional 45-foot chip van.

The rest of the equipment in this scenario is standard support equipment - farm trailers, service trucks, etc. These are required for each of the three scenarios.

Scenario 2. Cane-Grass-Woody Chopper Harvesting

This system is adaptable to almost all material, from grass to woody stems up to 6 cm and perhaps larger. The system is a single machine which cuts the stem, gathers it into a cutter, and loads wagons for removal from the fields.

The cutting machine shown is a Klaas Jaguar harvester, manufactured in Germany and widely used in Europe for silage operations. Conversations with other equipment manufacturers indicate that the machine is a derivative of a forage harvester, but has about \$55,000 in changes to accommodate larger, more woody stems. The engine is manufactured by Mercedes Benz, and the unit cuts down the material, chops it into particles less than 2", and blows the pieces over the top of the machine into a wagon behind it.

A demonstration of this machine was given in January 1994, near Bristol, UK, in a field of planted coppice willow about 2 years old. The indications are that it will harvest about 20 acres per day, at yields of 25 to 30 wet tons per acre. The company has a video showing the machine marching through 30-foot tall, 3" diameter poplars in Sweden.

According to one source, the machine evolved from a cane harvester. Cutting cane into pieces in the field, however, apparently is not effective, because of the sugar loss. Also, it was stated that the machine was much heavier than a billet cutter, and had trouble with getting stuck in the South Florida cane fields.

John Deere makes a forage harvester; the 6910 model with 430 HP costs about \$195,000. However, experience in Europe is that the John Deere is too light for the harder stems, and the cutter bar and chopper do not withstand the constant pounding of the material. Some farmers in the UK indicated that John Deere had done some preliminary work on coppice willow, but that the results were disappointing.

However, for the grass species, the John Deere must be considered. Parts will be easier to get, the machine is less expensive, and operation will probably be simpler. In addition, the forage harvesters can be used by conventional farming operations in the summer, helping to maximize the utilization of the equipment.

The primary disadvantage of this method is that the material is harvested green, with high moisture. For ethanol feedstock, this may not be a problem, but for combustion systems this represents a great disadvantage. One reduced in this chopped state, the material is difficult to store, and incurs losses from degradation.

For this harvesting system to be considered, the ground must support a machine in the weight range of 25,000 to 40,000 pounds. In the CSA's this may become a limiting factor.

Scenario 3. Grass Cut-Dry-Bale

In the case of grasses the technology required is very similar to existing farm systems. Farmers have been collecting hay for winter feed and forage for generations, and the market for equipment and technology is widespread and significant.

However, the anticipated biomass crop is different from the present-day hay crops. The 2-4 m height of the material is not typically encountered in haying, and the weight yields on a per acre basis make assumptions on fuel consumption and travel speed speculative.

Mislevy et. al. from the University of Florida performed harvesting trials in Ona, Florida, using this technique. The plots harvested were small, but the machine configuration was shown to be capable of accomplishing the task. The basic scenario involves cutting the grass, allowing it to field dry (either in windrows or in an even layer over the field), and then baling the material in round bales of 1,500 to 2,000 pounds each. The bales are then loaded on farm wagon and moved to roadside where they are loaded for transport or storage.

This operation offers several advantages. The equipment is well tested, widely used, and generally qualified operators are available. Parts and service are available, and equipment residual value is established. The machine weights are less, perhaps being able to work on areas that will not support heavy equipment. Storage of bales is fairly simple, and can be done outside with minimum cost.

The disadvantages must be viewed from the total system's perspective. The material is handled more often; this operation will be one of the higher labor options. Once the process is complete, the finished product - 1,500 pound bales - must be handled with special equipment. Baling requires a low moisture, and more exacting and less forgiving weather conditions.

The largest disadvantage is at the facility. Under this scenario, the processing plant does not receive a ready-to-use product. The round bales require another step of size reduction, and this increases the all-in cost of feedstock.

Summary

Table One of this report summarizes the information requested on equipment mixes, costs, and productivity, for each of the above scenarios. Based on the information provided from the Team members and a review of the information available on similar operations, the three scenarios above represent the best harvesting operations for the biomass stocks being contemplated in this study.

European bioenergy interests are pursuing the billet technology, because the storage of billets allows year-round material use with seasonal harvesting. Projects incorporating ethanol conversion are contemplating the chopper system, as it is inexpensive and delivers

a ready-to-use product. Small producers attempting to integrate existing farm operations on a pilot basis will probably prefer the cut/dry/bale method of biomass handling.

4. Identify the deliverables/products from the completed tasks.

This report is being delivered as one product of the investigations associated with this task. In addition, the following materials have been previously delivered or are being forwarded for review and possible inclusion in the compiled report to be prepared by the University of Florida:

Oral presentation of findings with slides and video presentations- completed November 15, 1994.

John Deere Agricultural Equipment Brochures

Table One.

HARVESTING MACHINERY SCENARIOS

SCENARIO 1. Cane-Woody- Harvested in Billets

	Machine Number								
	1	2	3	4	5	6	7	8	9
Machine Function	Cut/Billet	Chipper	Wagon	Wagon	Wagon	Wagon	Farm Tractor	Service Truck	Fuel Tank
Manufacturer	Austoff	Morbark	Varies	Varies	Varies	Varies	John Deer	Ford	Any
Model Number	7700	3036 E-Z	varies	varies	varies	varies	6300	F 350	
Specification	Track-type	Drum Type	25 ft.	25 ft.	25 ft.	25 ft.	4wd cab	One ton	500 gal
Horsepower	300	425					75		
Machine Purchase Cost	\$220,000	\$140,000	\$ 14,000	\$ 14,000	\$ 14,000	\$ 14,000	\$ 39,300	\$ 45,000	\$ 3,000
Estimated Useful Life, Hours	7500	5000					7500	7500	
Estimated Useful Life, Years	5	5	10	10	10	10	7	5	7
Machine Capacity, gr.tons per hour	80	50							
Machine Capacity, acres per hour	2								
Machine Availability-% of total time	85%	75%					90%	90%	
Expected Use in Hours per Year.	600	1200							
Expected Repair Costs per Year	\$ 9,000	\$ 28,000	\$ 1,000	\$ 1,000	\$ 1,000	\$ 1,000	\$ 2,500	\$ 1,500	
Fuel Type	Diesel						Diesel	Diesel	
Fuel Consumption per Hour	6	6					3	1	

HARVESTING MACHINERY SCENARIOS

SCENARIO 2. CANE-GRASS-WOODY-CHOPPER HARVESTING

	Machine Number						
	1	2	3	4	5	6	7
Machine Function	Cut/Chop	Wagon	Wagon	Wagon	Wagon	Tractor	Truck
Manufacturer	KLAAS	Varies	Varies	Varies	Varies	John Deere	Ford
Model Number	JAGUAR	varies	varies	varies	varies	6400	F 350
Specification	Willow hd.	covered	covered	covered	covered	4wd cab	One ton
Horsepower	250					85	
Machine Purchase Cost	\$285,000	\$ 22,000	\$ 22,000	\$ 22,000	\$ 22,000	\$ 41,600	\$ 45,000
Estimated Useful Life, Hours	7000					7500	7500
Estimated Useful Life, Years	6	10	10	10	10	7	5
Machine Capacity, gr.tons per hour	40						
Machine Capacity, acres per hour	2						
Machine Availability-% of total time	75%					90%	90%
Expected Use in Hours per Year	1500						
Expected Repair Costs per Year	\$ 23,000	1000	1000	1000	1000	2500	1500
Fuel Type	Diesel					Diesel	Diesel
Fuel Consumption per Hour	8					4	1

HARVESTING MACHINERY SCENARIOS

SCENARIO 3. GRASS-CUT/DRY/BALE SYSTEM

	Machine Number							
	1	2	3	4	5	6	7	8
Machine Function	Cutter	Farm Tractor	Farm Tractor	Windrow Rake	Round Baler	Tractor w/ Loader	Platform Wagon	Platform Wagon
Manufacturer	John Deer	John Deer	John Deer	John Deer	John Deer	John Deere	John Deer	John Deere
Model Number	240	6300	6300	700	535	6300	770	770
Specification	Rotary	4wd cab	4wd cab		5-6ft bales	4wd cab	14 ton	14 ton
Horsepower		75	75		75 req.	75		
Machine Purchase Cost	\$ 5,000	\$ 39,300	\$ 39,300	\$ 10,600	\$ 21,500	\$ 47,500	3600	3600
Estimated Useful Life, Hours	10000	7500	7500	10000	7000	7500	10000	10000
Estimated Useful Life, Years	10	7	7	10	7	7	10	10
Machine Capacity, gr.tons per hour	100			100	60			
Machine Capacity, acres per hour	3			3	2			
Machine Availability-% of total time	90%	90%	90%	90%	90%	90%	95%	95%
Expected Use in Hours per Year.	600	800	800	600	1000		300	300
Expected Repair Costs per Year	1000	\$ 2,500	\$ 2,500	1000	2000	\$ 2,500		
Fuel Type		Diesel	Diesel			Diesel		
Fuel Consumption per Hour		3	3			3		

Appendix F

Individual Crop/Soil Budgets

F.1 Individual Crop Budgets

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Sugarcane on Phosphatic Clay - Yield 22 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Chop	Billets
Herbicide	13.80			
Fertilizer		27.44		
Labor	100.00			
Seed	200.00			
Machinery	41.40	5.70	135.00	229.52
Machinery Labor	14.31	4.50	19.66	34.11
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	128.72	2.16		
<u>Total Operating Cost</u>	499.63	42.20	157.06	266.03
<u>Fixed Costs</u>				
Machinery	28.64	4.06	82.77	123.56
Supervision	38.76	6.17	23.74	38.72
Overhead	19.38	3.09	11.87	19.36
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		98.02		
<u>Total Fixed Costs</u>	88.48	134.74	121.78	185.04
Cost to transfer from field wagons to trailer			22.00	22.00
<u>Total Cost</u>	588.11	176.94	300.84	473.07
Cost per ton		8.04	13.67	21.50
¹ Average cost per ton when harvested with forage chopper			21.71	
² Average cost per ton when harvested as billets				29.54

Interest for establishment is amortized over the 6 year expected life of stand

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Sugarcane on Overburden Soil - Yield 18 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Chop	Billets
Herbicide	13.80			
Fertilizer		56.58		
Labor	100.00			
Seed	200.00			
Machinery	36.43	2.71	110.45	186.21
Machinery Labor	18.50	1.81	16.09	27.67
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	95.13	2.79		
<u>Total Operating Cost</u>	465.26	66.29	128.94	216.28
<u>Fixed Costs</u>				
Machinery	40.89	1.77	67.72	100.25
Supervision	41.96	6.23	19.43	31.41
Overhead	20.98	3.12	9.71	15.71
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		142.70		
<u>Total Fixed Costs</u>	105.53	177.22	100.26	150.77
Cost to transfer from field wagons to trailer			18.00	18.00
<u>Total Cost</u>	570.79	243.31	247.20	385.05
<u>Cost per ton</u>		13.52	13.75	21.39
¹ Average cost per ton when harvested with forage chopper			27.35	
² Average cost per ton when harvested as billets				34.91

³ Interest for establishment is amortized over the 4 year expected life of stand

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Sugarcane on Crop Land Soil - Yield 18 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Chop	Billets
Herbicide	6.90			
Fertilizer		64.12		
Labor	100.00			
Seed	200.00			
Machinery	33.91	2.00	110.45	186.21
Machinery Labor	15.11	1.68	16.09	27.67
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	91.10	2.79		
<u>Total Operating Cost</u>	448.42	72.99	128.94	216.28
<u>Fixed Costs</u>				
Machinery	37.48	1.63	67.72	100.25
Supervision	39.34	6.94	19.43	31.41
Overhead	19.67	3.47	9.71	15.71
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		136.65		
<u>Total Fixed Costs</u>	98.19	172.09	100.26	150.77
Cost to transfer from field wagons to trailer			18.00	18.00
<u>Total Cost</u>	546.61	245.08	247.20	385.05
Cost per ton		13.62	13.75	21.39
¹ Average cost per ton when harvested with forage chopper			27.35	
² Average cost per ton when harvested as billets				35.01

³ Interest for establishment is amortized over the 4 year expected life of stand

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Elephantgrass on Phosphatic Clay - Yield 18 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Hay	Chop
Herbicide	13.80			
Fertilizer		27.44		
Labor	100.00			
Seed	200.00			
Machinery	30.83	5.70	103.00	110.45
Machinery Labor	14.31	4.50	84.79	16.09
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	124.34	2.16		
<u>Total Operating Cost</u>	484.68	42.20	190.19	128.94
<u>Fixed Costs</u>				
Machinery	28.64	4.06	101.29	67.72
Supervision	38.76	6.17	28.91	19.43
Overhead	19.38	3.09	14.45	9.71
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		95.53		
<u>Total Fixed Costs</u>	88.48	132.25	148.05	100.26
Cost to transfer from field wagons to trailer			--	18.00
<u>Total Cost</u>	573.16	174.45	338.24	247.20
<u>Cost per ton</u>		9.69	18.79	13.73
¹ Average cost per ton when harvested as hay			28.48	
² Average cost per ton when harvested with forage chopper				23.42

³ Interest for establishment is amortized over the 6 year expected life of stand

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Elephantgrass on Overburden Soil - Yield 18 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Hay	Chop
Herbicide	13.80			
Fertilizer		56.58		
Labor	100.00			
Seed	200.00			
Machinery	36.43	2.71	103.00	110.45
Machinery Labor	18.50	1.81	84.79	16.09
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	136.18	2.79		
<u>Total Operating Cost</u>	506.31	66.29	190.19	128.94
<u>Fixed Costs</u>				
Machinery	40.89	1.77	101.29	67.72
Supervision	41.96	6.23	28.91	19.43
Overhead	20.98	3.12	14.45	9.71
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		101.97		
<u>Total Fixed Costs</u>	105.53	136.49	148.05	100.26
Cost to transfer from field wagons to trailer			--	18.00
<u>Total Cost</u>	611.84	202.78	338.24	247.20
Cost per ton		11.27	18.79	13.73
¹ Average cost per ton when harvested as hay			30.06	
² Average cost per ton when harvested with forage harvester				25.00

³ Interest for establishment is amortized over the 6 year expected life of stand

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Elephantgrass on Crop Land Soil - Yield 18 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Hay	Chop
Herbicide	6.90			
Fertilizer		64.12		
Labor	100.00			
Seed	200.00			
Machinery	33.91	2.00	103.00	110.45
Machinery Labor	15.11	1.68	84.79	16.09
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	127.54	2.79		
<u>Total Operating Cost</u>	484.86	72.99	190.19	128.94
<u>Fixed Costs</u>				
Machinery	37.48	1.63	101.29	67.72
Supervision	39.34	6.94	28.91	19.43
Overhead	19.67	3.47	14.45	9.71
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		97.18		
<u>Total Fixed Costs</u>	98.19	132.62	148.05	100.26
Cost to transfer from field wagons to trailer			--	18.00
<u>Total Cost</u>	583.05	208.61	338.24	247.20
<u>Cost per ton</u>		11.59	18.79	13.73
¹ Average cost per ton when harvested as Hay			30.38	
² Average cost per ton when harvested with forage chopper				25.32

³ Interest for establishment is amortized over the 6 year expected life of stand

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Leucaena on Phosphatic Clay - Yield 16 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Chop	Billets
Herbicide	17.12			
Fertilizer				
Labor				
Seed	75.00			
Machinery	24.43	.19	87.00	278.81
Machinery Labor	12.84	.27	13.59	34.46
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	77.31			
<u>Total Operating Cost</u>	208.10	2.86	102.99	315.67
<u>Fixed Costs</u>				
Machinery	23.40	.19	46.26	123.57
Supervision	15.28	2.07	14.68	43.68
Overhead	7.64	1.03	7.34	21.84
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		25.61		
<u>Total Fixed Costs</u>	48.02	52.30	71.68	192.49
Cost of transfer from field wagons to trailer			16.00	
<u>Total Cost</u>	256.12	55.16	190.67	508.16
Cost per ton		3.45	11.92	31.76
¹ Average cost per ton when harvested with forage chopper			15.37	
² Average cost per ton when harvested as billets - includes chipping dried billets				35.21

³ Interest for establishment is amortized over the 10 year expected life of stand

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Leucaena on Overburden Soil - Yield 15 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Chop	Billets
Herbicide	17.12			
Fertilizer		25.60		
Labor				
Seed	75.00			
Machinery	24.43	.64	82.42	257.60
Machinery Labor	12.84	.52	12.87	31.75
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	78.24	.96		
<u>Total Operating Cost</u>	209.03	30.12	97.69	291.75
<u>Fixed Costs</u>				
Machinery	23.40	.50	43.82	113.81
Supervision	15.28	2.73	13.91	40.32
Overhead	7.64	1.36	6.96	20.16
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		25.78		
<u>Total Fixed Costs</u>	48.02	53.77	68.09	177.69
Cost of transfer from field wagons to trailer			16.00	---
<u>Total Cost</u>	257.05	83.90	181.78	469.44
Cost per ton		5.59	12.12	31.30
¹ Average cost per ton when harvested with forage chopper			17.71	
² Average cost per ton when harvested as billets - includes chipping dried billets				36.89

³ Interest for establishment is amortized over the 10 year expected life of stand

Estimated Cost/Acre for Establishing Maintaining and Harvesting
Leucaena on Crop Land Soil - Yield 12 dry tons/acre

	Establishment	Maintenance	Harvest ¹	Harvest ²
<u>Operating Costs</u>			Chop	Billets
Herbicide	17.12			
Fertilizer		29.52		
Labor				
Seed	75.00			
Machinery	22.04	.64	66.40	237.26
Machinery Labor	10.99	.52	10.37	30.03
Pickup truck (\$.14/mile)	1.40	2.40	2.40	2.40
Interest ³	75.11	1.10		
<u>Total Operating Cost</u>	201.66	34.18	79.17	269.69
<u>Fixed Costs</u>				
Machinery	20.64	.50	35.30	107.83
Supervision	14.58	3.12	11.21	37.51
Overhead	7.29	1.56	5.60	18.76
Pickup truck (\$.17/mile)	1.70	3.40	3.40	3.40
Land Rent		20.00		
Annual Share of Establishment Cost		24.59		
<u>Total Fixed Costs</u>	44.21	53.17	55.51	167.50
Cost of transfer from field wagons to trailer			12.00	---
<u>Total Cost</u>	245.87	87.35	146.68	437.19
Cost per ton		7.28	12.22	36.43
¹ Average cost per ton when harvested with forage chopper			19.50	
² Average cost per ton when harvested as billets - includes chipping dried billets				43.71

³ Interest for establishment is amortized over the 10 year expected life of stand

Estimated Cost/Acre for Growing and Harvesting
Forage Sorghum on Phosphatic Clay - Yield 11 dry tons/acre

	Est. & Maint.	Harvest ¹	Harvest ²
<u>Operating Costs</u>		Billet	Chop
Herbicide	17.12		
Fertilizer	27.44		
Seed	8.96		
Machinery	28.48	115.48	68.73
Machinery Labor	16.04	17.16	10.01
Pickup truck (\$.14/mile)	2.40	2.40	2.40
Interest	3.27		
<u>Total Operating Cost</u>	103.71	135.04	81.14
<u>Fixed Costs</u>			
Machinery	26.21	62.17	42.14
Supervision	14.47	19.48	12.09
Overhead	7.23	9.74	6.04
Pickup truck (\$.17/mile)	3.40	3.40	3.40
Land Rent	20.00		
<u>Total Fixed Costs</u>	71.31	94.79	63.67
Cost to transfer from field wagons to trailers		11.00	11.00
<u>Total Cost</u>	175.02	240.83	155.81
Cost per ton	15.91	21.89	14.16
¹ Average Cost per ton when harvested with billet harvester		37.80	
² Average Cost per ton when harvested with forage chopper			30.07

Estimated Cost/Acre for Growing and Harvesting
Forage Sorghum on Overburden Soil - Yield 10 dry tons/acre

	Est. & Maint.	Harvest ¹	Harvest ²
<u>Operating Costs</u>		Billets	Chop
Herbicide	17.12		
Fertilizer	56.58		
Seed	8.96		
Machinery	36.56	114.04	61.36
Machinery Labor	16.64	16.95	8.94
Pickup truck (\$.14/mile)	2.40	2.40	2.40
Interest	3.59		
<u>Total Operating Cost</u>	141.85	133.39	72.70
<u>Fixed Costs</u>			
Machinery	35.17	61.39	37.62
Supervision	17.10	19.24	10.79
Overhead	8.55	9.62	5.40
Pickup truck (\$.17/mile)	3.40	3.40	3.40
Land Rent	20.00		
<u>Total Fixed Costs</u>	84.22	93.65	57.21
Cost to transfer from field wagons to trailers		10.00	10.00
<u>Total Cost</u>	226.07	237.04	139.91
<u>Cost per ton</u>	22.61	23.70	13.99
¹ Average Cost per ton when harvested with billet harvester		46.31	
² Average Cost per ton when harvested with forage chopper			36.15

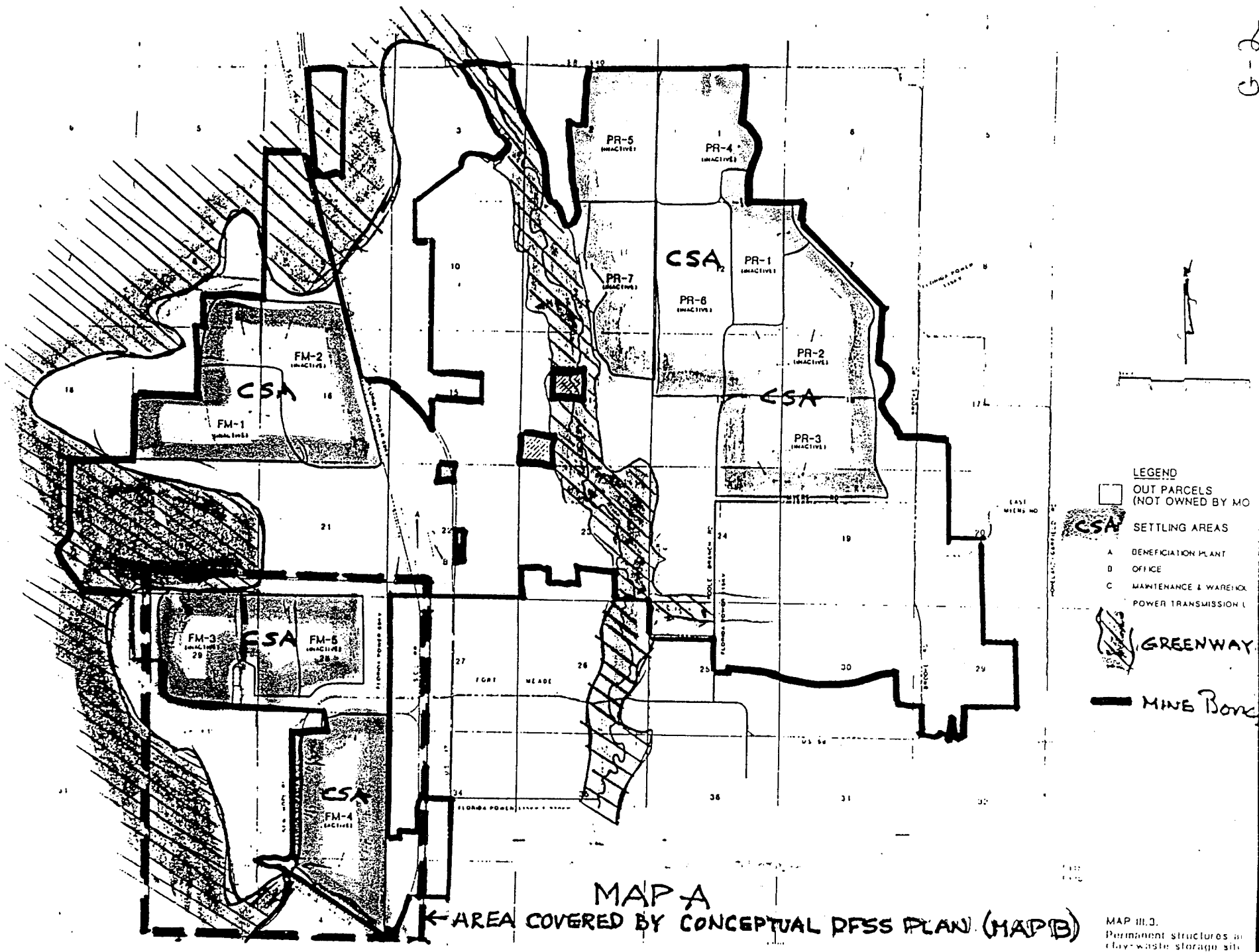
Estimated Cost/Acre for Growing and Harvesting
Forage Sorghum on Crop Land - Yield 10 dry tons/acre

	Est. & Maint.	Harvest ¹	Harvest ²
<u>Operating Costs</u>		Billets	Chop
Herbicide	17.12		
Fertilizer	56.58		
Seed	8.96		
Machinery	36.68	114.04	61.36
Machinery Labor	15.10	16.95	8.94
Pickup truck (\$.14/mile)	2.40	2.40	2.40
Interest	3.59		
<u>Total Operating Cost</u>	140.43	133.39	72.70
<u>Fixed Costs</u>			
Machinery	32.95	61.39	37.62
Supervision	16.54	19.24	10.79
Overhead	8.27	9.62	5.40
Pickup truck (\$.17/mile)	3.40	3.40	3.40
Land Rent	20.00		
<u>Total Fixed Costs</u>	81.16	93.65	57.21
Cost to transfer from field wagons to trailers		10.00	10.00
<u>Total Cost</u>	221.59	237.04	139.91
Cost per ton	22.16	23.70	13.99
¹ Average Cost per ton when harvested with billet harvester		45.86	
² Average Cost per ton when harvested with forage chopper			36.15

Appendix G

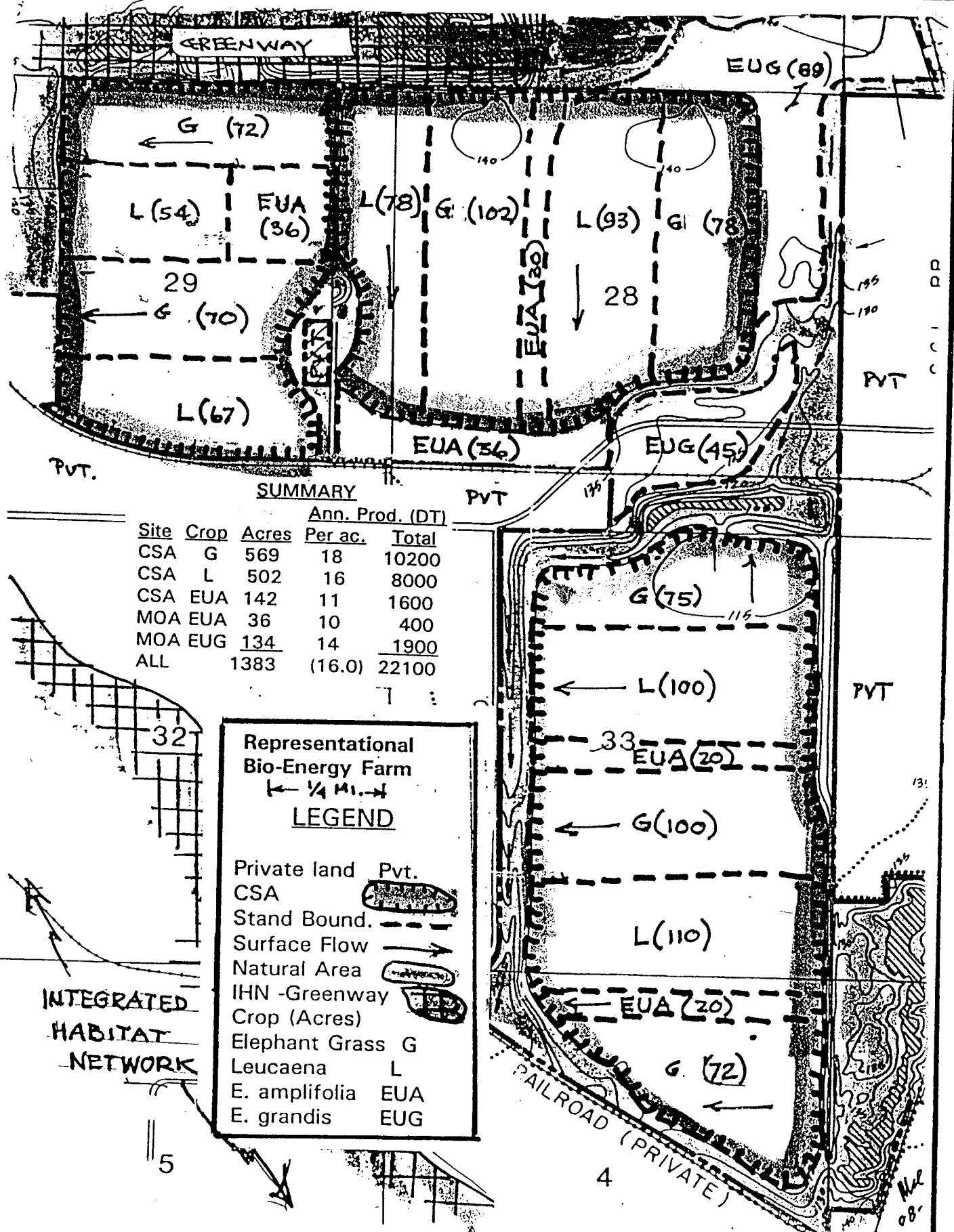
DFSS Best Management Practices

G.1 Conceptual DFSS Plan



MAP III.3.
Permanent structures on
clay waste storage site

G.2 Representation of Bioenergy Farm



MAP B

G.3 Draft Environmental Plan Review List

DRAFT ENVIRONMENTAL PLAN SENT FOR REVIEW AND COMMENT

to:

(List revised August 1, 1994)

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US Fish & Wildlife Service, 1875 Centruy Rd. Atlanta, GA 30345

Fl. Sen. Rick Dantzler, Dist S-17

Fl. Sen. James Hargrett, Dist S-21

Fl. Rep. Dean Saunders, Dist. H-63

Fl. Rep. John Laurent, Dist. H-66

U.S. Sen Bob Graham*

U.S. Sen Connie Mack*

U.S. Rep Chas. T. Canady, 12th Dist.

* Comments received by August 15.

Appendix H

Environmental Concerns Processing and Conversion of Biofuels

H.1 Table of Contents

Instruction Guide for Certification Applications

Florida Department of Environmental Regulation

Twin Towers Office Bldg. • 2600 Blair Stone Road • Tallahassee, Florida 32399-2400

Lawton Chiles, Governor

Carol M. Browner, Secretary



INSTRUCTION GUIDE
FOR
CERTIFICATION APPLICATIONS:
ELECTRICAL POWER PLANT SITE, ASSOCIATED FACILITIES,
AND ASSOCIATED TRANSMISSION LINES
DER Form 17-1.211(1)

10/21/83

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RADIUM 226 IMPACTS, POLK COUNTY BIOFUELS

Worst case scenario

Assumptions:

	<u>Ra-226 content</u>
Clay settling pond site	24 pCig ⁻¹
Species - Pennisitum and leucaena, 90% crop	0.11 "
Eucalyptus, 10% crop	unknown
Maximum average for crop	0.15 "

Ash content = 5% of dry matter weight

All radium goes into ash (non-volatilized)

Ash will be recycled on soils where crop is grown

Ra 226 content of resulting ash will be 20 times that of the biofuel used.

$$= 20 \times .15 = 3 \text{ pCig}^{-1}$$

Ra 226 content of ash will be about 12% of that of the soil from which produced.

$$= \frac{3 \text{ (ash)}}{24 \text{ (soil)}} = 12.5\%$$

Conclusion: Ash is not hazardous

No adverse impacts will result from recycling on the soils where grown.



STATE OF FLORIDA
DEPARTMENT OF HEALTH AND REHABILITATIVE SERVICES

March 16, 1995

W. V. McCONNELL
1023 San Luis Road
Tallahassee, FL 32304

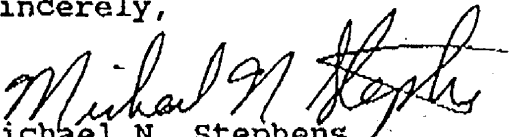
Dear Mr. McConnell:

We acknowledge receipt of your letter dated December 15, 1994 and fax dated February 22, 1995 regarding disposal of ash containing radium 226 from natural uptake by plants.

Ash containing less than 5 picocuries per gram of radium 226, disposed of by returning to the land, should not create a radiological health hazard.

If you have any questions, please contact us at (904)487-2437.

Sincerely,


Michael N. Stephens
Public Health Physicist
Radioactive Materials Section
Office of Radiation Control

MNS



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IV

345 COURTLAND STREET, N.E.
ATLANTA, GEORGIA 30365

4APT-AEB

JAN 31 1995

Mr. W. V. McConnell
1023 San Luis Road
Tallahassee, FL 32304

SUBJ: Project Proposal to Produce Electricity by Incineration of
Biomass Containing Radium-226 in Polk County, FL

Dear Mr. McConnell:

Your letter of January 3, 1995, with enclosures, requested that the Environmental Protection Agency (EPA) provide comments on the referenced proposal. After reviewing your submittal, we have the following remarks:

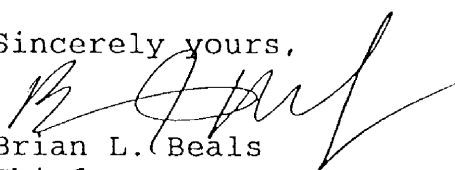
At this time, the proposed project is not subject to a federal radionuclide emissions standard; however, should the State of Florida require that you obtain a radiation license, your facility may become subject to 40 CFR Part 61 - National Emission Standards for Hazardous Air Pollutants (NESHAPS).

Your letter also requested our opinion regarding the public health hazard of emissions resulting from the combustion of biomass material containing radium-226. Unfortunately, we cannot make a determination based upon the information contained in your submittal. For example, the enclosures did not contain a thorough description of the conversion process, annual throughput or pollution control equipment. We recognize that this matter will probably be addressed by the State of Florida during their evaluation of the need for radiation licensing.

Finally, in response to your request for data on the radioactive content of coal, we have enclosed a risk assessment on coal-fired boilers.

If you should have further questions regarding this letter, please contact Mr. Joel Huey of my staff at 404/347-3555, voice mail box 4170.

Sincerely yours,


Brian L. Beals
Chief
Source Evaluation Unit
Air Enforcement Branch
Air, Pesticides & Toxics
Management Division

Enclosures

cc: William A. Passetti, Florida Office of Radiation Control *Printed on Recycled Paper*

H-11

H.2 Wastewater Processing/Conversion & Disposal

INTRODUCTION

A successful dedicated biomass to ethanol production and conversion system which is both economically and environmentally sustainable requires the application of a host of component technologies in a holistic and integrated manner which minimizes economic risk for the investment. Figure 1 shows one schematic representation of a dedicated biomass feedstock (DBF) and biomass ethanol conversion facility (BECF) which is classified into four dependent component systems shown as production, harvesting, storage, and conversion. The objectives of sub-task 3B, the conversion and processing environmental assessment, concerns mainly the BECF but is linked to the DBF system through the possibility of recovering and utilizing byproducts which can enhance DBF production while providing an economically viable and necessary point of disposition for byproducts which must leave the BECF. If the primary output of such a system is the production of the liquid fuel ethanol, which leaves the facility in an almost pure state, then every other material input to the BECF will eventually require some final disposition. The most suitable final use of each byproduct which maximizes its value is the most optimal for sustainability.

Note that not all of the inputs and losses for the component systems can be completely controlled through process design though the goal is to minimize the cost of both controllable inputs and losses. For the BECF, while minimizing inputs is useful for economical ethanol production, there is also a significant incentive to minimize wasting the "necessary" byproduct outputs through treatment and conversion to the most valuable utilization.

Figure 1: An example of a dedicated biomass feedstock to ethanol system. (See attached Fig.)

DEFINITIONS AND PROCESS DESCRIPTIONS

Ethanol Production

A more detailed schematic of the unit process steps required to produce ethanol within the BECF is depicted in figure 2. Since the total quantity (mass and volume) of the "whole" stillage leaving the distillation column is an order of magnitude larger than any of the other unit process "losses", then the opportunity for minimizing waste at the BECF should start with byproduct recovery with this waste stream. However, each of the preceding unit processes has a significant impact on the quantity and quality of this stillage wastewater stream so optimal utilization of the stillage can benefit by an understanding of how hydrolysis, saccharification, fermentation and distillation effect the stillage byproduct.

Figure 2. The biomass ethanol conversion facility (BECF) component system inputs and outputs. (See attached Fig.)

Existing and Potential Feedstocks

Fermentation

- Batch

- Continuous

- Immobilization

- Ethanol Producing Cultures

 - S. Cerevisiae*

 - Zymmobilis*

 - Genetically engineered

 - E. coli*

 - Zymmobilus*

- Toxicity

- Sterility

Saccharification

- alpha amylase

 - Ca⁺⁺ and pH 5.5

- gluco-amylase

 - pH 4.5

- pH and salinity dependence

Hydrolysis and Pretreatment

- Pretreatment

 - Mechanical

 - Steam Explosion

 - Thermal-mechanical

 - TAMP

- Enzymatic

- Acid

- Solvent hydrolysis

- Combinations

- Over-liming and Detoxification

STILLAGE CHARACTERIZATION, PHYSICAL TREATMENT AND BYPRODUCT RECOVERY

Figure 3. Stillage processing and utilization options. (See attached fig.)

Stillage Production

Table 1. Stillage production literature values. (This table still requires data entry!)

Stillage Characteristics

whole stillage

thin stillage

BOD

Organic Compounds

Priority Pollutants

Heavy Metals

Salts

Nutrients

Volatile Organic Compounds

Refractory organics

SO₄

Table 2. Stillage characterization from conventional feedstocks. (See attached Table.)

Table 3. Stillage characterization from cellulosic feedstocks. (See attached Table.)

Physicochemical Recovery Unit Processes

Gravity Separation and Centrifugation

Evaporation

Effects

Thermal Recompression

10-50% volume increase

Mechanical Recompression

Membrane Separation

Ion-exchange

Other Selective Exchange Processes

Energy by Combustion

Byproducts from Physicochemical Recovery Processes

Yeast

Animal Feed

Process Water

Evaporator Condensate

- Fertilizers
 - C/N, Na⁺, K
- Glycerol and Secondary Metabolite Products
- Tannins, Soluble Lignins, Hemicellulose, Furfural
- Salts and Heavy Metals

- Untreated Stillage Utilization
 - Recycling
 - Secondary Yeast Production
 - Land-application and Nutrient Recovery

BIOLOGICAL STILLAGE TREATMENT

RBC	Aerobic Treatment
	Processes
	oxidation ponds, extended aeration, activated sludge, trickling filter,
	Capacity
	Footprint
	Treatment Efficiency
	Energy Consumption
	Low O ₂ solubility at high temperature
	Sludge Production
	Overloading
	Toxicity
	Sludge Byproduct Recovery
	Anaerobic Treatment
	Processes
Capacity	
Treatment Efficiency	

Table 4. Anaerobic treatment of stillage from conventional feedstocks. (This table still requires data entry!)

Table 5. Anaerobic treatment of stillage from conventional feedstocks. (See attached Table.)

- Biogas Production
- Sludge Production
- Overloading
- Toxicity
- Sludge Byproduct Recovery

Soil Treatment and Nutrient Utilization

STILLAGE AND EFFLUENT UTILIZATION AND FINAL DISPOSAL

- Marine
- Surface Water
- Ground Water Injection
- POTW
- Irrigation and Effluent Utilization
 - Nutrients
 - Salts
 - Heavy Metals
 - Phytotoxicity

ECONOMICS

Table 6. Economics of anaerobic treatment of stillage. (This table still requires data entry!)

SUMMARY AND CONCLUSIONS

As an enhancement to the principal project objectives of determining economic and technical feasibility of a biomass energy dedicated feedstock supply system centered on phosphatic clay soils resulting from mining activities in Central Florida, this component served to investigate methods to process and utilize the significant byproduct streams associated with ethanol production projected as an option for liquid fuel production. Since a preliminary review of ethanol production wastewater characteristics and previous experience revealed a consensus toward anaerobic digestion as an economically viable and sustainable byproduct recovery scheme, much of this effort focused on examining the aspects of biomass to ethanol conversion and effluent disposition which are expected to impact technical feasibility of anaerobic digestion. To a practical extent, an attempt was made to study the role of feedstock, hydrolysis method, in-plant recycling, microbial toxicity, byproduct recovery, feed recovery, nutrient recovery, single-cell protein production, reactor type, biogas yield, phytotoxicity and sustainability, had in byproduct treatment and utilization options.

Some of the specific objectives were:

1. To determine the expected characteristics of stillage wastes from biomass to ethanol production processes and feedstocks significant to the Central Florida region.

2. To determine the expected treatability and some of the processing options of the predicted stillage.
3. To determine some of the more suitable post-processing schemes which maximize high-value byproduct recovery and/or long term sustainability of the dedicated biomass feedstock supply system.
4. To determine additional information and research needs required to adequately predict the economic and environmental consequences of biomass to ethanol conversion and associated by-product recovery and utilization options.
5. To document the findings of this effort.

The approach applied to achieve component objectives was to perform a detailed investigation of ethanol production and byproduct recovery processes which were expected to result in economic or environmental impacts. To accomplish this effort, a detailed review of the applicable literature was performed. In addition, local, national, and international expertise from academia, industry, and government organizations was sought for input and guidance toward knowledge not immediately available from traditional sources.

An effort was made to synthesis related industrial experience which is believed to be relevant to a dedicated biomass feedstock to ethanol system in the Central Florida region. Specific industrial activities considered include: corn and grain ethanol production, sugar cane ethanol production, molasses ethanol production, pulp and paper production, fermentation industry's wastewater treatment and land application, crop production utilizing similar wastewaters, and research and development of economic ligno-cellulosic hydrolysis methods. Efforts also pursued laboratory, pilot-scale, and field and full-scale experience in biomass ethanol production, agronomic studies on ethanol waste utilization, and in anaerobic digestion of stillage from a number of ethanol feedstocks.

While the principal aims of some of the objectives were not entirely fulfilled, this effort has resulted in significant progress toward an appreciation of the potential impacts of biomass ethanol production. There is a need for further information and specific areas of research require further study are included. And, in documenting this effort it is believed this objective is realized. Some specific conclusions from this effort are:

1. Existing research supports the application of anaerobic digestion for biomass to ethanol stillage treatment and biogas recovery.
2. Research also indicates that land application of effluents for nutrient recovery may allow enhanced crop production.
3. Options for enhancing stillage utilization and byproduct recovery exist such as feed production through single cell protein and/or algae, and in the recovery of useful organic compounds of industrial significance.

RESEARCH NEEDS FOR PROCESS ENVIRONMENTAL AND ECONOMIC ASSESSMENT

From many of the conclusions of this effort, areas of knowledge which appear to

require further investigation are apparent to the authors. While some of the research currently underway both in the U.S. and in other countries at the forefront of commercially viable biomass to ethanol production (eg. Canada, Brazil, New Zealand, etc.), is not immediately available to the authors, it is believed that results of these efforts are not widely available and specific research efforts resulting in information dissemination would help government and industry progress toward economically and environmentally sustainable biomass to ethanol energy production systems. Some of these recommendations include:

1. Hydrolysis stillage characterization data should be obtained for pertinent feedstocks, hydrolysis methods, and fermentation schemes and these results should be considered during feedstock and process selection/optimization.
2. As final selection of feedstock/process is approached, corresponding hydrolysis stillage treatability studies should be performed prior to preliminary process design and cost estimation.
3. As stillage treatability studies are performed, a simultaneous examination of effluent phytotoxicity on pertinent soils and cropping systems should allow methods for ameliorating such effects and to estimate the costs of these methods.
4. Conversion process design and implementation must consider the role of input chemicals and their fate to assure sustainability of the system. Both long-term use of Na (pH control), and the effects of heavy metals (as losses from corrosion of equipment) on the sustainability of the biomass cropping system should be addressed.

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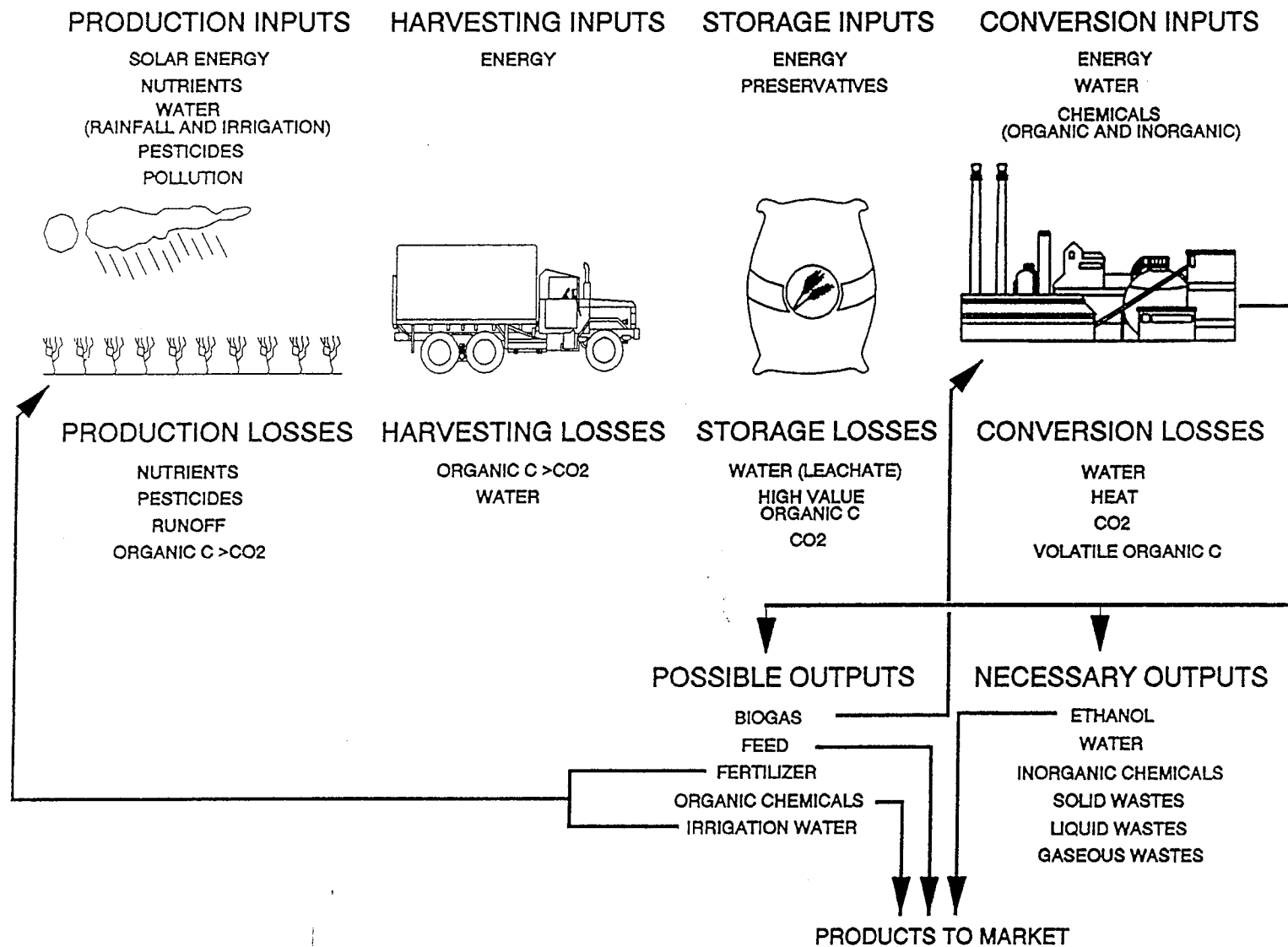
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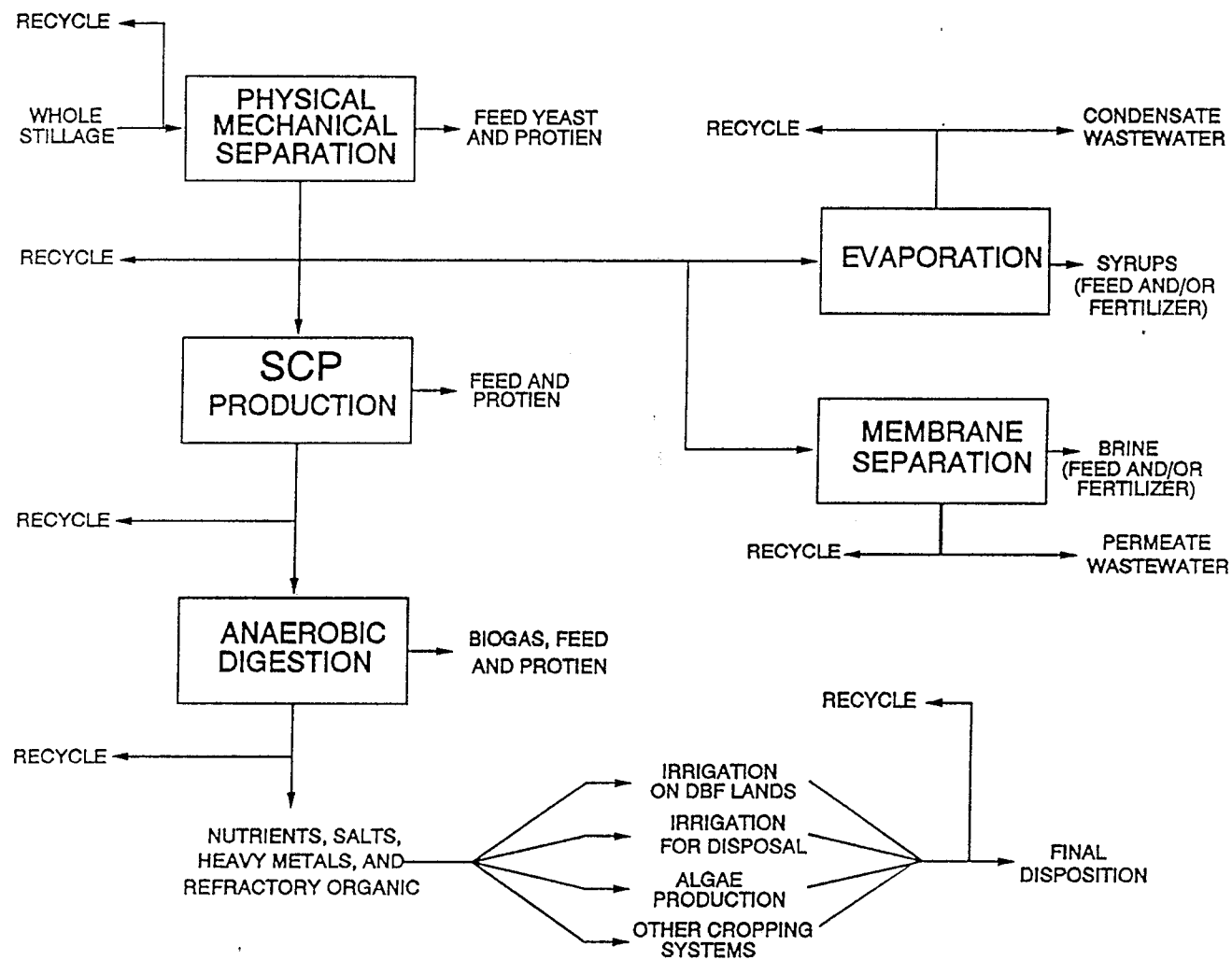
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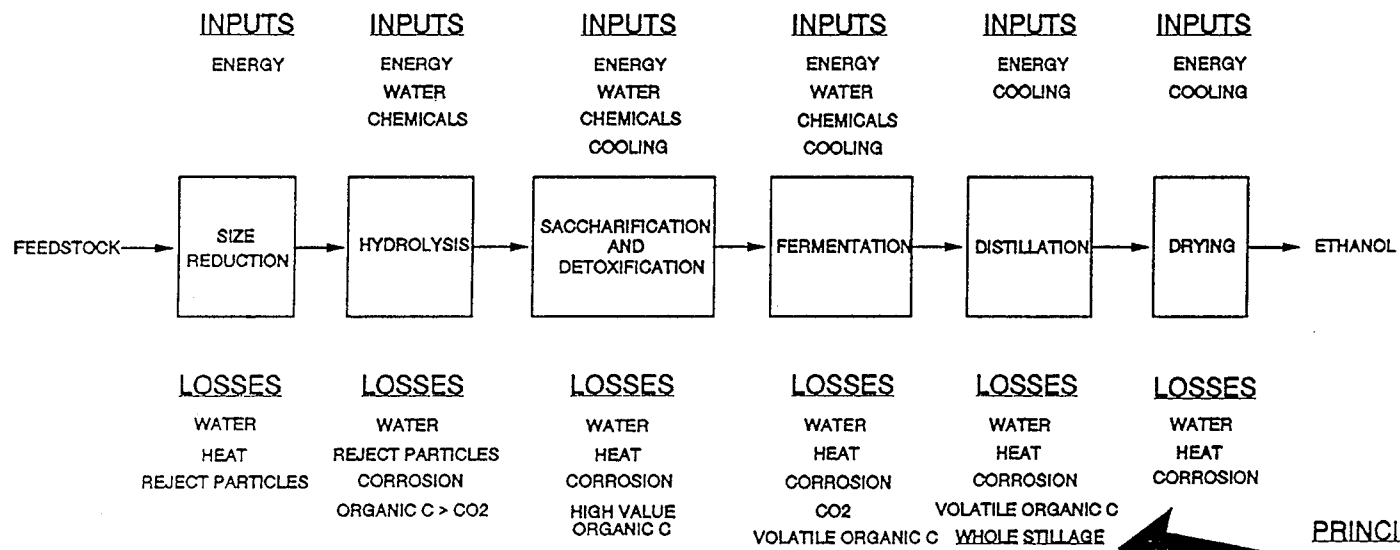
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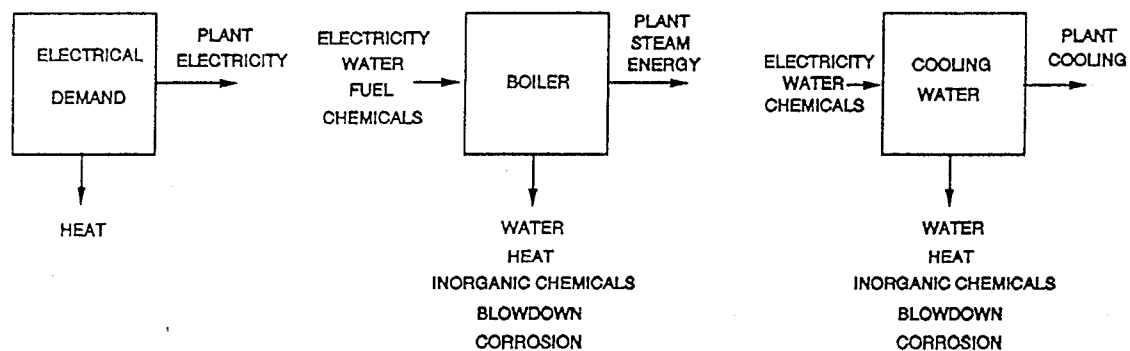


Table 3B-1. Stillage production.

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Table 3B-2. Stillage characterization from conventional feedstocks.

Feedstock	Stillage Yield ton/ton	BOD (COD) g/L	N (total) mg/L	P (total) mg/L	K mg/L	Total S as SO ₄ mg/L	pH	References
Cane molasses (stored)	nd	27.5 (64.0)	1300	nd	nd	2800	4.5-5.5	Bazua et al. (1991)
Beet sugar molasses	nd	nd (115.8)	56	175	nd	1042	6.69	Boopathy and Tilche (1990)
Fresh cane juice	nd	nd (26.0)	1190	320	2100	1470	3.91	Callander and Barford (1983)
Cane molasses	nd	nd (24.6)	812	29	1980	607	4.17	Casarini et al. (1987)
Cane molasses	nd	nd (22.5)	1192	247	nd	nd	5.2	Cho (1983)
Fresh cane juice	nd	15 (22)	400	58	nd	400	3.5	Driessen et al. (1994)
Cane molasses	nd	12 (25)	400	200	800	nd	3.5	Haandel and Cavalcanti (1994)
Grapes	nd	nd (26)	nd	nd	800	nd	3.0-3.2	Henry et al. (1988)
Cane molasses	nd	nd (100)	2500	300	1750	700	4.6-5.1	Riera et al. (1985)
Cane molasses	nd	40 (80)	nd	45	4013	nd	4.5-5.0	Silverio et al. (1986)
Cane molasses	nd	nd (31.5)	370	24	1300	420	3.9	Souza et al. (1992)
Unknown (distillery)	nd	40 (nd)	345	38.8	nd	69.5	4.4	Srivastava and Sahai (1987)
Corn	nd	26.9 (64.5)	755	1170	nd	nd	3.3-4.0	Stover et al. (1984)
Cane molasses (rum)	nd	42 (105)	1450	100	nd	4000	4.0-5.0	Szendrey and Dorion (1986)
Milo grain	nd	40.4 (45.5)	nd	nd	nd	nd	4.1	Hunter (1988)

nd - no data

H-35

Table 3B-3. Stillage characterization from cellulosic feedstocks.

Feedstock/Process	Stillage Yield ton/ton Feedstock	BOD (COD) g/L	N (total) mg/L	P (total) mg/L	K mg/L	Total S as SO ₄ mg/L	pH	References
<i>Pinus radiata</i> /DA-SF	16.7	13.2 (25.5)	95.3	10.3	nd	600	4.5-5.0	Liquid Fuels Trust Board (no date)
<i>Eucalyptus</i> /DA	nd	nd (22.5)	200	40	nd	260-360	5.8-6.3	Good et al. (1982)
RDF/TS-DA-SF	nd	nd (38.1)	nd	nd	nd	nd	5.5	TVA (1993)
MSW/TS-DA-SF	nd	32.1 (72.0)	140	nd	nd	nd	5.5	Broder (1995)
RDF/nd	6.7	6.5 (nd)	nd	nd	nd	nd	nd	USEPA (1978)
Mixed (woody)/nd	nd	26.7 (72.0)	nd	nd	nd	589	nd	CH ₂ MHILL (1991)
Mixed (herbaceous)/nd	nd	56.2 (140)	nd	nd	nd	602	nd	"
Mixed (biomass)/nd	nd	46.8 (119)	nd	nd	nd	617	nd	"
MSW/nd	nd	20.9 (61)	nd	nd	nd	599	nd	"
Hardwood/TS-DA	nd	nd (19.1)	2800	74	nd	900	nd	Strickland et al. (1986)

nd - no data

DA - Dilute Acid

SF - Saccharomyces Fermentation

RDF - Refuse Derived Fuel

MSW - Municipal Solid Waste

TS - Two Stage

CH₂MHILL (1991) values are predicted estimates

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Table 3B-4. Anaerobic treatment of stillage from conventional feedstocks.

Feedstock/Process	Reactor Type (size - L)	Influent BOD (COD) g/L	HRT (days)	Temp (°C)	Treatment Efficiency % removed BOD (COD)	Methane Yield (Prod) L/g COD (L/L/day)	References

nd - no data

UASB - Upflow Anaerobic Sludge Blanket

UFAF - Upflow Anaerobic Filter

CSTR - Continuously Stirred Reactor

Table 3B-5. Anaerobic treatment of stillage from cellulosic feedstocks.

Feedstock/Process	Reactor Type (size - L)	Influent BOD (COD) g/L	HRT (days)	Temp (°C)	Treatment Efficiency % removed BOD (COD)	Methane Yield (Prod) L/g COD (L/L/day)	References
<i>Pinus radiata</i> /DA-SF	UASB (8.0)	13.9 (27.5)	2.0	37	92 (82)	(4.0)	Liquid Fuels Trust Board (no date)
<i>Eucalyptus</i> /DA	UFAF (2.0)	nd (22.5)	2.1	35	nd (86.6)	0.4 (2.7)	Good et al. (1982)
"	"	" "	2.25	55	nd (84.4)	0.38 (2.4)	"
"	CSTR (2.0)	" "	9.5	35	nd (85.5)	0.4 (0.6)	"
Hardwoods/TS-DA-SF	CSTR (1.0)	nd (19.1)	nd	35	nd	nd	Strickland et al. (1986)

nd - no data

UASB - Upflow Anaerobic Sludge Blanket

UFAF - Upflow Anaerobic Filter

CSTR - Continuously Stirred Reactor

Table 3B-6. Economics.

[illegible]

Appendix I

NREL Field Laboratory Reports

I.1 Biomass Samples Tested at NREL Laboratory

CHEMICAL ANALYSIS & TESTING (CAT) Task Analytical Report								Analysis No. 95-044		Page 1 of 1	
Project Title: Analysis of Savant-Vincent Herbaceous Samples											
NREL In-House <input type="checkbox"/>				Current Subcontractor <input type="checkbox"/>				CRADA <input type="checkbox"/>		Other <input checked="" type="checkbox"/>	
Name of Project Contact Person: J. Mielenz						Date Work Completed: 3/15/95					
EL Notebook: #1641, p025						Date Samples Delivered: 2/24/95					
Samples from Feedstock Lot No.: n/a						Actual Hours Spent: 10					
Summary of Requested Work: 95% ethanol extraction, complete compositional analysis.						Proposed Approach: Standard LAPs by validated outside laboratory and by in house analyst.					
Work Required: Sample Prep <input checked="" type="checkbox"/> Acid Digest <input checked="" type="checkbox"/> HPLC <input checked="" type="checkbox"/> YSI <input type="checkbox"/> GC <input type="checkbox"/> Other: 95% EtOH extraction											
Results and Comments <input type="checkbox"/> % As Received <input checked="" type="checkbox"/> % Dry Weight <input type="checkbox"/> mg/mL <input type="checkbox"/> Other:											
Sample		TS	EX	G	X	GA	A	M	LKL	LAS	AT
Savant-Vincent Sugarcane, washed cake, 95-044-385 <i>press cake sample</i>	ave	99.47	n/a	39.26	22.94	1.06	2.47	0.89	21.38	2.18	4.74
	sd	0.03	--	0.27	0.04	0.23	0.13	0.14	0.07	0.00	0.01
95% EtOH extracted Sugarcane, washed cake, 95-044-382	ave	100.0	n/a	43.74	24.83	1.06	2.45	1.18	20.17	1.79	4.76
	sd	0.00	--	0.09	0.06	0.01	0.10	0.14	0.01	0.05	0.14
95% EtOH extracted Sugarcane, washed cake, 95-044-382, back-calculated to include extractives	ave	n/a	14.67	37.32	21.19	0.90	2.09	1.01	17.21	1.53	4.06
	sd	---	0.38	0.08	0.05	0.01	0.09	0.12	0.01	0.04	0.12
	ave										
	sd										
	ave										
	sd										
	ave										
	sd										

=arabinose; AT=total ash; C=mass % carbon; EX=95% ethanol extractives; G=glucose; G-YSI=glucose by YSI; GA=galactose; H=mass % hydrogen; LAS=acid soluble lignin; LKL=Klason lignin; M=mannose; N=mass % nitrogen; n/a=not applicable; nd=not detected; nr=not requested; P=protein; ST=starch; TS=total solids; X=xylose; * =calculated from nitrogen measured by CHN.

Name(s) of CAT Staff Working on Project: Larry Brown <i>Larry Brown</i>	Reviewed by: Tina Ehrman <i>Tina Ehrman</i>
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CHEMICAL ANALYSIS & TESTING (CAT) Task Analytical Report

Analysis
No.
95-048

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Project Title: Analysis of Savant-Vincent Herbaceous Samples (ET01)

NREL In-House

☐

Current Subcontractor

☐

CRADA

☐

Other

☒

Name of Project Contact Person: J. Mielenz

Date Work Completed: 3/21/95

NREL Notebook: #1641, p026

Date Samples Delivered: 3/06/95

Samples from Feedstock Lot No.: N/A

Actual Hours Spent: 12

Summary of Requested Work: Complete compositional analysis before and after 95% EtOH extraction.

Proposed Approach: Standard LAPs by validated outside laboratory and by in house analyst.

Work Required: Sample Prep ☒ Acid Digest ☒ HPLC ☒ YSI ☐ GC ☐ Other: ☐

Results and Comments ☐ % As Received ☒ % Dry Weight ☐ mg/mL ☐ Other:

Sample		TS	EX	G	X	GA	A	M	LKL	LAS	AT
1 Elephant Grass, 95-048-387	ave	97.56	n/a	43.29	22.49	0.86	6.41	1.48	20.94	1.94	4.61
	sd	0.10	---	0.14	0.35	0.02	0.14	0.04	0.05	0.02	0.10
2 95% EtOH extracted Elephant Grass, 95-048-388	ave	100.0	n/a	44.87	23.42	0.90	6.75	1.61	20.11	1.63	4.08
	sd	0.00	---	0.18	0.19	0.01	0.13	0.03	0.09	0.06	0.16
95% EtOH extracted Elephant Grass, 95-048-388, back-calculated to include extractives	ave	n/a	9.02	40.32	21.31	0.82	6.14	1.46	18.30	1.48	3.71
	sd	---	0.59	0.16	0.17	0.01	0.12	0.03	0.08	0.05	0.15
3 Leucaena, 95-048-389	ave	93.42	n/a	45.22	14.74	2.26	3.33	10.14	23.70	2.34	2.15
	sd	0.10	---	0.20	0.03	0.07	0.11	0.23	0.83	0.02	0.04
4 95% EtOH extracted leucaena, 95-048-390	ave	100.0	n/a	46.65	14.56	2.41	3.51	10.36	23.37	1.92	1.60
	sd	0.00	---	0.11	0.08	0.05	0.18	0.08	0.23	0.01	0.02
95% EtOH extracted leucaena, 95-048-390, back-calculated to include extractives	ave	n/a	8.34	42.76	13.35	2.21	3.22	9.50	21.42	1.76	1.47
	sd	---	0.09	0.10	0.07	0.05	0.16	0.07	0.21	0.01	0.02

A=arabinose; AT=total ash; C=mass % carbon; EX=95% ethanol extractives; G=glucose; G-YSI=glucose by YSI; GA=galactose; H=mass % hydrogen; LAS=acid soluble lignin; LKL=Klason lignin; M=mannose; N=mass % nitrogen; n/a=not applicable; nd=not detected; nr=not requested; P=protein; ST=starch; TS=total solids; X=xylose; *=Not enough sample to run in duplicate.

Name(s) of CAT Staff Working on Project: Larry Brown

Reviewed by: Ray Ruiz

Larry Brown

Ray Ruiz

CHEMICAL ANALYSIS & TESTING (CAT) Task Analytical Report

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Results and Comments ☐ % As Received ☒ % Dry Weight ☐ mg/mL ☐ Other:

Sample		TS	EX	G	X	GA	A	M	LKL	LAS	AT
Sugarcane presscake, 95-048-391 <i>Dried Presscake</i>	ave	96.95	n/a	41.30	23.71	0.63	6.03	1.45	20.08	2.73	4.11
	sd	0.02	---	0.01	0.20	0.00	0.06	0.08	0.04	0.06	0.04
95% EtOH extracted sugarcane presscake, 95-048-392	ave	100.0	n/a	42.78	24.89	0.68	6.17	1.33	19.20	2.52	3.82
	sd	0.00	---	0.08	0.26	0.02	0.09	0.06	0.10	0.04	0.04
95% EtOH extracted sugarcane presscake, 95-048-392, back-calculated to include extractives	ave	n/a	10.99	38.08	22.15	0.61	5.49	1.18	17.09	2.24	3.40
	sd	---	0.37	0.07	0.23	0.02	0.08	0.05	0.09	0.04	0.04
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=arabinose; AT=total ash; C=mass % carbon; EX=95% ethanol extractives; G=glucose; G-YSI=glucose by YSI; GA=galactose;
=mass % hydrogen; LAS=acid soluble lignin; LKL=Klason lignin; M=mannose; N=mass % nitrogen; n/a=not applicable; nd=not
detected; nr=not requested; P=protein; ST=starch; TS=total solids; X=xylose; *=Not enough sample to run in duplicate.

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				5e. TASK NUMBER BB04.7610	
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